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PROVISIONAL APPLICATION COVER SHEET

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TITLE OF THE INVENTION (280 characters max)

DRIVING METHOD FOR AN ELECTROPHORETIC DISPLAY WITH HIGH FRAME RATE AND LOW POWER CONSUMPTION

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Respectfully submitted,

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Word/wk2003/wk electrophoretic high frame rate low power.doc

Driving method for an electrophoretic display with high frame rate and low power consumption

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(26 June2003)

Aim

Driving method of achieving accurate greyscale and increased number of grey levels is proposed for an electrophoretic display using high frame rate with yet low power consumption. DRIVING WAVEFORMS FOR VARIOUS GREYSCALE IMAGE TRANSITIONS ARE INTENTIONALLY ALIGNED IN TIME IN SUCH THAT A VOLTAGE CHANGE DIRECTLY FROM -15V TO +15V OR FROM +15V TO -15V IS AVOIDED DURING THE SAME FRAME TIME PERIOD. Since the (peak) power is proportional to the square voltage-change, i.e. $P=C\times(\Delta V)^2$, a frame time of as short as ¼ of the "standard" frame time is allowed to keep the same low power consumption. The availability of the short frame time is particularly important for improving the greyscale accuracy at higher temperatures and for increasing the number of grey levels.

Back ground and problem to be solved

Driving an electrophoretic display, pulse width-modulation (PWM) is preferably used because of the cheap price of the drivers. Using a driving waveform, the greyscale accuracy is limited by the minimum frame time, which is usually ("standard") 20ms. A shorter frame time is recently achieved, which is about 8 ms. Electrophoretic display is based on the motion of charged particles under external electric field. The switching time will change with changing temperature because of the change of the particle mobility and/or the viscosity of the fluid. With present E-ink materials, the switching time decreases with increasing temperature. The driving voltage waveforms developed for room temperature must be extended to the higher temperatures. A possible method is to reduce the frame time (PHNL020844) by for example scaling, requesting very short frame time!! In addition, to achieve an increased number of grey levels, a still shorter frame time is needed for further improving the greyscale accuracy. However, the use of relative short frame time asks more power. In particular, when the source driver IC has to operate between negative and positive voltages in the same short frame scanning, an unacceptably high peak power will be requested. Here, a method is proposed for improving the greyscale accuracy using a high frame rate with yet low power consumption.

Proposed solution

In this invention disclosure, a driving method of achieving accurate greyscale and increase number of grey levels is proposed for an electrophoretic display using high frame rate with yet low power consumption. DRIVING WAVEFORMS FOR VARIOUS GREYSCALE IMAGE TRANSITIONS ARE INTENTIONALLY ALIGNED IN TIME IN SUCH THAT A VOLTAGE CHANGE DIRECTLY FROM -15V TO +15V OR FROM +15V TO -15V IS AVOIDED DURING THE SAME FRAME TIME PERIOD. Since the (peak) power is proportional to the square voltage-change, i.e. $P=C\times(\Delta V)^2$, a frame time of as short as ¼ of the "standard" frame time is allowed to keep the same low power consumption. The availability of

the short frame time is particularly important for improving the greyscale accuracy at higher temperatures and for increasing the number of grey levels.

It is applicable for any driving schemes including rail-stabilized driving schemes, in which the driving pulses consist of reset pulses and greyscale driving pulses. The reset pulse is the voltage pulse moving particles to one of the two extreme optical states and the greyscale driving pulse is the voltage pulse sending the display/pixel to the desired final optical state. In the following embodiments, the rail-stabilized driving as disclosed in PHNL030091 is used for the explanation of this invention.

In Figure 1, example waveforms are illustrated for image transitions from White (W) to Dark grey (G1), Black (B) to Light grey (G2), G2 to G1 and G2 to G2 using the rail-stabilized driving scheme as disclosed in PHNL030091. Each waveform consists of four portions: shake 1, reset, shake 2 and drive. Both shake 1 and shake 2 can be implemented by data-independent "hardware" shaking, i.e. all pixels on the display receive simultaneously the shaking signal independent of data on individual pixels. In this way, the power consumption can be minimized. However, the dada-dependent reset and drive pulses are supplied per frame by frame. Apparently, the

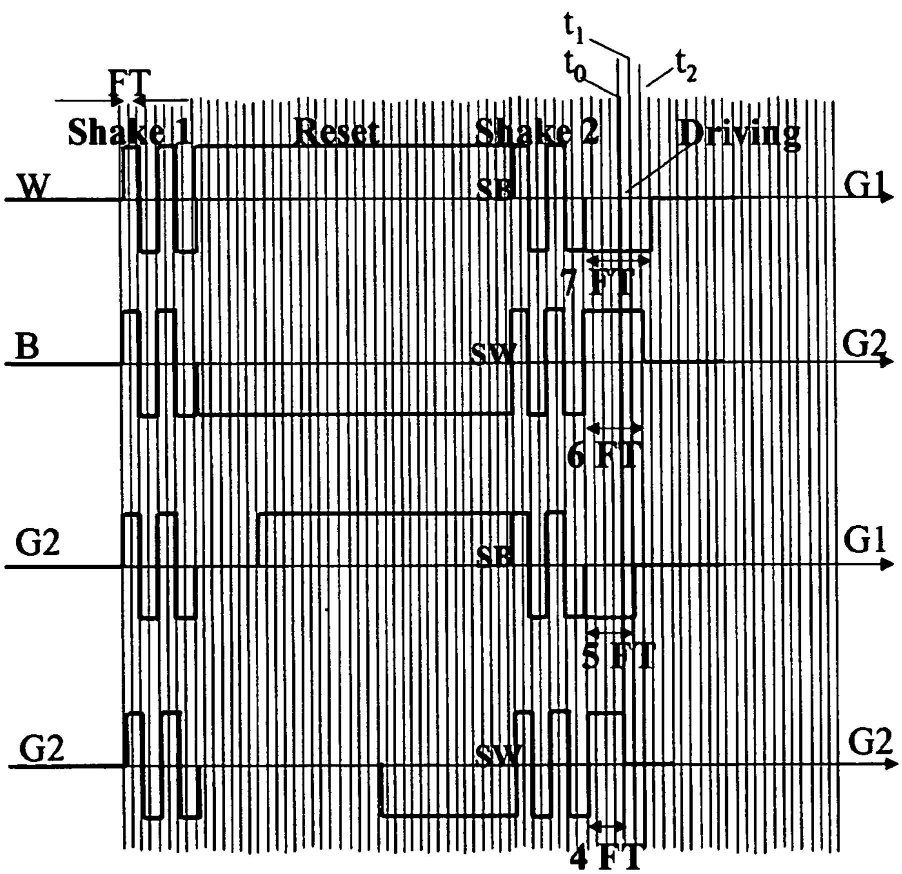


Figure 1: Example waveforms for image transitions White (W) to Dark grey (G1), Black (B) to Light grey (G2), G2 to G1 and G2 to G2 using the rail-stabilized driving scheme disclosed in PHNL030091. A short frame time (FT) is used and a high peak power is expected at the frame time periods between t_0 and t_1; t_1 and t_2.

reset pulse is less sensitive to the choice of the frame time but the greyscale drive pulse is extremely sensitive to the choice of the frame time because the greyscale accuracy in each transition is mainly determined by the drive pulse period. We therefore focus on the drive portion in the following discussion. In the image transitions of Figure 1, the greyscale drive pulse time period varies from 4-frame time (FT) to 7-FT. In the same time, some of the greyscale drive pulses have positive voltages and others have negative voltages. For the first 4 FT period, one can consider these four frames as a single LONG "standard" frame using a single scan, keeping the low power consumption (although source driver operating at negative and positive voltages). In the 5th (between t_0 and t_1) and 6th (between $t_1$and t_2) frame periods, a single scan with the minimum (short) frame time FT is required during which both negative and positive voltages have to be supplied by the source driver, requesting UNACCEPTABLE peak power.

In Figure 2, the first embodiment of this invention is given, in which the same waveforms as used in Figure 1 are presented but now part of the greyscale drive pulse in the B to G2 transition is delayed by 3 frames. In the 5th (between t_0 and t_1) frame, a single scan with the minimum FT must be used. However, now the source driver experiences only a voltage change from 0 to –15V, the power consumption remains low. In the 6th and 7th frames, two scans with 1 FT or preferably one scan with 2 FT

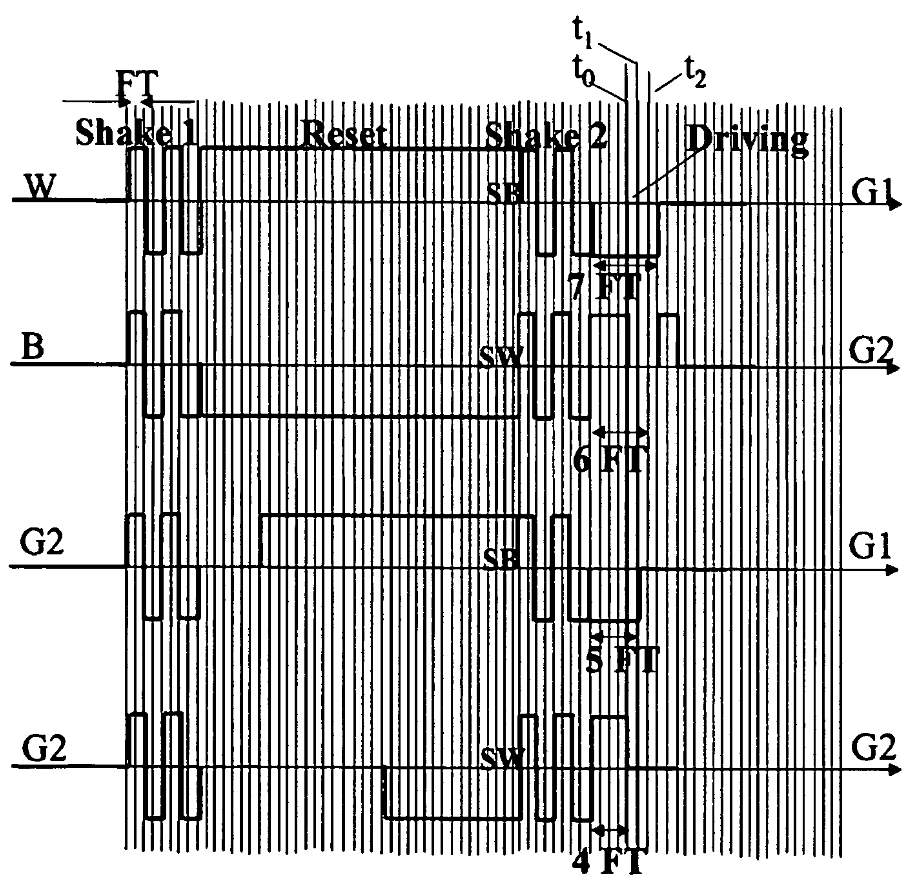


Figure 2: The same waveforms for the image transitions as in Figure 1 using short frame times. Now, part of the drive pulse in the transition B to G2 is delayed by 3 frames so a high peak power is avoided according to the embodiment 1 of this invention.

may be used, during which the source driver again experiences only 0 to −15V. In the 8th and 9th frame, two scans with 1 FT or preferably one scan with 2 FT may be used, during which the source driver experiences only 0 to +15V. In this way, a high peak power is avoided because the (peak) power is proportional to the square voltage-change, i.e. $P=C\times(\Delta V)^2$.

In Figure 3, the embodiment 2 of this invention is given, in which the same waveforms as used in Figure 1 are presented but now part of the greyscale drive pulses in both W to G1 and G2 to G1 transitions are delayed by 2 frames. In the 5th and 6th frame (between t_0 and t_2), two scans with 1 FT or preferably one scan with 2 FT may be used, during which the source driver experiences only 0 to +15V. In the 7th frame, a single scan with the minimum FT is used. Since the source driver experiences only a voltage change from 0 to −15V, the power consumption remains low. In the 8th and 9th frames, two scans with 1 FT or preferably one scan with 2 FT may be used, during which the source driver experiences only 0 to -15V. In this way, a high peak power is avoided.

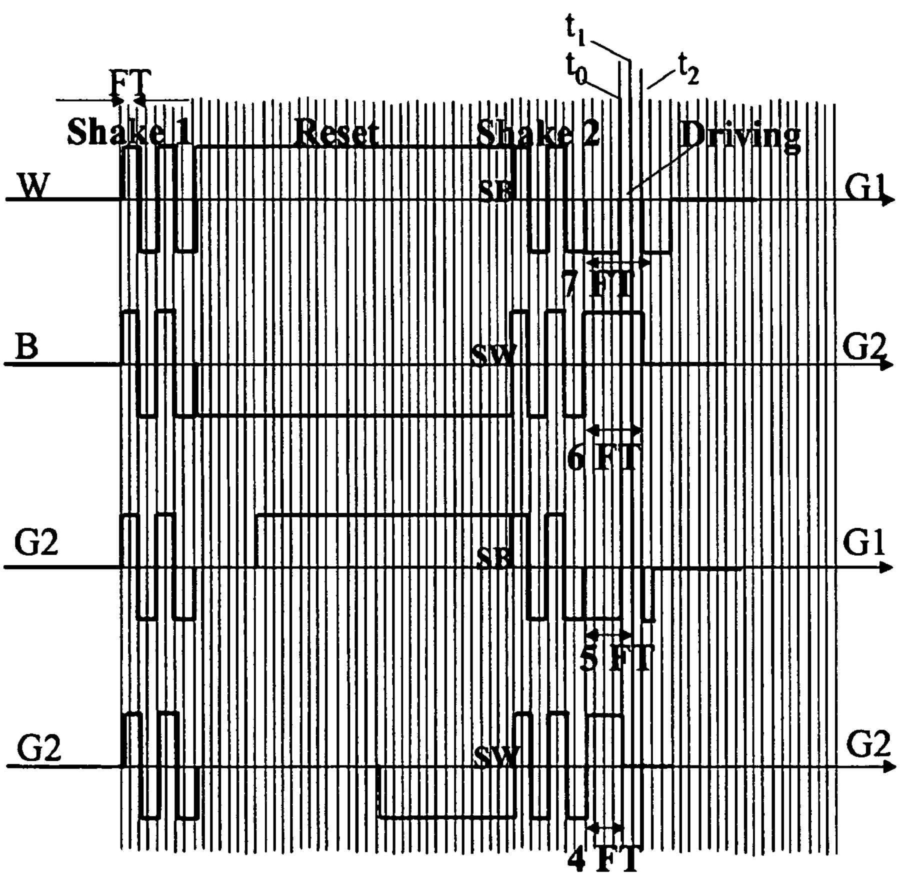


Figure 3: The same waveforms for the image transitions as in Figure 1 using short frame times. Now, part of the drive pulses in both transitions W to G1 and G2 to G1 is delayed by 2 frames so a high peak power is avoided according to the embodiment 2 of this invention.

The embodiment 3 of this invention is given in Figure 4, which is derived from embodiment 2 but a frame with V=0 is used after the complete of the drive positive drive pulse in B to G2 transition and prior to the start of the negative drive pulses in W to G1 and G2 to G1 transitions. This may further reduce the load of the source driver, so power consumption is reduced.

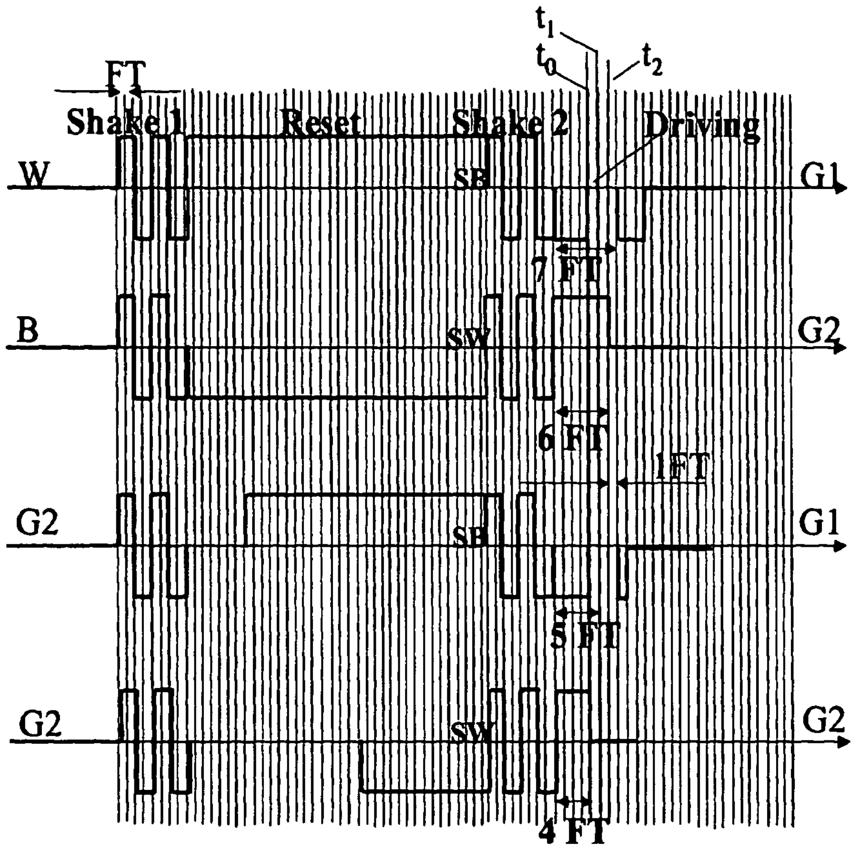


Figure 4: The same waveforms as in Figure 3 using short frame times, but a frame with V=0 is introduced after the complete of the drive positive drive pulse in B to G2 transition and prior to the start of the negative drive pulses in W to G1 and G2 to G1 transitions, according to the embodiment 3 of this invention.

Addendum to Provisional Filing for ID no. 699234

Applicants' docket no.'s PHNL020844 (EP02078823.8, filed September 16, 2002), PHNL 030091 (EP 03100133.2, filed January 23, 2003), PHNL 020441 (EP 02077017.8, filed May 24, 2002) and PHNL030661 (EP 03101705.6, filed June 11, 2003) are attached and are incorporated and made a part of this application.

The invention is not limited to any particular driving concept or concepts.

The invention may be implemented in passive matrix as well as active matrix electrophoretic displays.

The display can be any bi-stable display. The invention can be implemented in any bi-stable display, which display does not consume power while the image substantially remains on the display after an image update.

The invention may be implemented for color scales as well as grayscale.

Electrophoretic display unit

The invention relates to an electrophoretic display unit, to a display device comprising an electrophoretic display unit, to a method for driving an electrophoretic display unit and to a processor program product for driving an electrophoretic display unit.

Examples of display devices of this type are: monitors, laptop computers, personal digital assistants (PDAs), mobile telephones and electronic books, electronic newspapers and electronic magazines.

A prior art electrophoretic display unit is known from international patent application WO 99/53373. This patent application discloses an electronic ink display comprising two substrates, with one of the substrates being transparent and having a common electrode (also known as counter electrode) and with the other substrate being provided with pixel electrodes arranged in rows and columns. A crossing between a row electrode and a column electrode is associated with a pixel. The pixel is formed between a part of the common electrode and a pixel electrode. The pixel electrode is coupled to the drain of a transistor, of which the source is coupled to the column electrode and of which the gate is coupled to the row electrode. This arrangement of pixels, transistors and row and column electrodes jointly forms an active matrix. A row driver (select driver) supplies a selection signal for selecting a row of pixels and a column driver (data driver) supplies data signals to the selected row of pixels via the column electrodes and the transistors. The data signals correspond to data to be displayed, and form, together with the selection signal, a (part of a) driving signal for driving one or more pixels.

Furthermore, an electronic ink is provided between the pixel electrode and the common electrode provided on the transparent substrate. The electronic ink comprises multiple microcapsules of about 10 to 50 microns in diameter. Each microcapsule comprises positively charged white particles and negatively charged black particles suspended in a fluid. When a positive field is applied to the pixel electrode, the white particles move to the side of the microcapsule directed to the transparent substrate, and the pixel becomes visible to a viewer. Simultaneously, the black particles move to the pixel electrode at the opposite

side of the microcapsule where they are hidden from the viewer. By applying a negative field to the pixel electrode, the black particles move to the common electrode at the side of the microcapsule directed to the transparent substrate, and the pixel appears dark to a viewer. Simultaneously, the white particles move to the pixel electrode at the opposite side of the microcapsule where they are hidden from the viewer. When the electric fields are removed, the display device remains in the acquired state and exhibits a bi-stable character.

To reduce the dependency of the optical response of the electrophoretic display unit on the history of the pixels, preset data signals are supplied before the data-dependent signals are supplied. These preset data signals comprise pulses representing energies which are sufficient to release the electrophoretic particles from a static state at one of the two electrodes, but which are too low to allow the particles to reach the other electrode. Because of the reduced dependency on the history, the optical response to identical data will be substantially equal, regardless of the history of the pixels. The underlying mechanism can be explained by the fact that, after the display device is switched to a predetermined state, for example a black state, the electrophoretic particles come to a static state. When a subsequent switching to the white state takes place, the momentum of the particles is low because their starting speed is close to zero. This results in a high dependency on the history which requires a long switching time to overcome this high dependency. The application of the preset data signals increases the momentum of the electrophoretic particles and thus reduces the dependency (and allows a shorter switching time).

Each update of the pixels of the electrophoretic display unit requires, per row, a row driving action for supplying the selection signal to the row for selecting (driving) this row, and a column driving action for supplying pulses, like , for example, pulses of the preset data signals and pulses of the data-dependent signals, to the pixels. The time-interval required for driving all pixels of all rows once (by driving each row one after the other and by driving all columns simultaneously once per row) is called a frame period.

So, during a first set of frames, the pulses of the preset data signals are supplied to the pixels, with each pulse having a duration of one frame period. The first pulse , for example, has a positive amplitude, the second one a negative amplitude, and the third one a positive amplitude etc. (alternating amplitudes). As long as the duration of these pulses is relatively short, the pulses do not change the gray value displayed by the pixel.

During a second set of frames comprising one or more frame periods, one or more pulses of the data-dependent signals are supplied. The data-dependent signals have a duration of zero, one, two to , for example, fifteen frame periods. Thereby, a data-dependent

signal having a duration of zero frame periods , for example, corresponds with the pixel displaying full black (in case the pixel already displayed full black; in case of displaying a certain gray value, this gray value remains unchanged when being driven with a pulse having a duration of zero frame periods, in other words when being driven with a pulse having a zero amplitude). A data-dependent signal having a duration of fifteen frame periods comprises fifteen subsequent pulses and , for example, corresponds with the pixel displaying full white, and a data-dependent signal having a duration of one to fourteen frame periods comprises one to fourteen subsequent pulses and , for example, corresponds with the pixel displaying one of a limited number of gray values between full black and full white.

Due to all frames each having the same fixed duration, the driving of the electrophoretic display unit is highly inflexible. The number of gray values is limited, and cannot be increased, with the difference between two subsequent gray values being rather large.

The known electrophoretic display unit is disadvantageous, inter alia, due to the driving of the electrophoretic display unit being relatively inflexible.

It is an object of the invention, inter alia, of providing an electrophoretic display unit with a relatively flexible driving.

Furthers objects of the invention are, inter alia, providing a display device comprising an electrophoretic display unit with a relatively flexible driving, and providing a method for driving an electrophoretic display unit and a processor program product for driving an electrophoretic display unit, for use in (combination with) an electrophoretic display unit with a relatively flexible driving.

An electrophoretic display unit according to the invention comprises

- an electrophoretic display panel comprising a pixel;
- a controller for generating a driving signal in dependence of an input image by selecting frame periods from a sequence of frame periods for providing pulses to the pixel, at least two frame periods of the sequence of frame periods having a different frame period duration; and
- drivers for, in response to the driving signal, providing the pulses to the pixel.

By introducing sequences of frame periods in which at least two frame periods of the sequence of frame periods have a different frame period duration and by selecting frame periods from a sequence of frame periods for providing , for example, pulses of the

data-dependent signals to the pixels, the number of possible gray values has been increased, and the gray values can be generated more accurately. Compared to prior art embodiments offering a fixed frame period for making a number of combinations of frames by adding a frame or not during which the part of the driving signal is to be supplied, according to the invention one or more shorter frames and one or more longer frames can be combined arbitrarily. During the rest of the frames not chosen for driving a pixel, this pixel keeps its gray value due to the bi-stable character.

An embodiment of an electrophoretic display unit according to the invention is defined by claim 2. By delaying a start of a frame period, a frame period duration of a preceding frame period is adapted (extended with the delay time used for delaying the start of the frame period).

An embodiment of an electrophoretic display unit according to the invention is defined by claim 3. By supplying , for example, pulses of the data-dependent signals with a positive amplitude and with a negative amplitude, the net driving result is the difference between the pulses with the positive and negative amplitudes, to further increase the number of possible gray values.

An embodiment of an electrophoretic display unit according to the invention is defined by claim 4. By storing information about the frame periods to be selected for the driving signal, the necessary one or more frame periods are automatically selected when selecting one of the driving signals to be supplied to a pixel.

An embodiment of an electrophoretic display unit according to the invention is defined by claim 5. Shaking pulses , for example, correspond with the pulses of the preset data signals discussed before. The driving pulses, for example, correspond with the pulses of the data-dependent signals discussed before. Reset pulses precede the driving pulses to further improve the optical response of the electrophoretic display unit, by defining a fixed starting point (fixed black or fixed white) for the driving pulses. Alternatively, reset pulses precede the driving pulses to further improve the optical response of the electrophoretic display unit, by defining a flexible starting point (black or white, to be selected in dependence of and closest to the gray value to be defined by the following driving pulses) for the driving pulses. The information is stored per combination of driving pulses, each combination corresponding to a possible gray value to be generated by the driving pulses.

An embodiment of an electrophoretic display unit according to the invention is defined by claim 6. In this embodiment the information is stored per combination of reset

pulses, each combination corresponding to a possible gray value to be generated by the reset pulses.

The display device as claimed in claim 7 may be an electronic book, while the medium for storing information may be a memory stick, integrated circuit, a memory or other storage device for storing, for example, the content of a book to be displayed on the electrophoretic display unit.

Embodiments of a method according to the invention and of a processor program product according to the invention correspond with the embodiments of an electrophoretic display unit according to the invention.

The invention is based upon an insight, inter alia, that prior art with fixed frame periods results in a relatively inflexible driving, and is based upon a basic idea, inter alia, that selections of (combinations of) different frame periods with different frame period durations make the driving more flexible.

The invention solves the problem, inter alia, by providing an electrophoretic display unit with a relatively flexible driving, and is advantageous, inter alia, in that the number of possible gray values is increased and in that the gray values can be generated more accurately.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments(s) described hereinafter.

In the drawings:

Fig. 1 shows (in cross-section) a pixel;

Fig. 2 shows diagrammatically an electrophoretic display unit;

Fig. 3 shows a waveform for driving an electrophoretic display unit;

Fig. 4 shows two data-dependent signals according to the invention constructed via a sequence of frame periods according to the invention comprising different frame periods with different frame period durations; and

Fig. 5 shows twenty data-dependent signals according to the invention constructed via a sequence of frame periods according to the invention comprising different frame periods with different frame period durations.

The pixel 11 of the electrophoretic display unit shown in Fig. 1 (in cross-section) comprises a base substrate 2, an electrophoretic film (laminated on base substrate 2) with an electronic ink which is present between two transparent substrates 3,4 of, for example, polyethylene. One of the substrates 3 is provided with transparent pixel electrodes 5 and the other substrate 4 is provided with a transparent common electrode 6. The electronic ink comprises multiple microcapsules 7 of about 10 to 50 microns in diameter. Each microcapsule 7 comprises positively charged white particles 8 and negatively charged black particles 9 suspended in a fluid 10. When a positive field is applied to the pixel electrode 5, the white particles 8 move to the side of the microcapsule 7 directed to the common electrode 6, and the pixel becomes visible to a viewer. Simultaneously, the black particles 9 move to the opposite side of the microcapsule 7 where they are hidden from the viewer. By applying a negative field to the pixel electrode 5, the black particles 9 move to the side of the microcapsule 7 directed to the common electrode 6, and the pixel appears dark to a viewer (not shown). When the electric field is removed, the particles 8,9 remain in the acquired state and the display exhibits a bi-stable character and consumes substantially no power.

The electrophoretic display unit 1 shown in Fig. 2 comprises a display panel DP comprising a matrix of pixels 11 at the area of crossings of row or selection electrodes 41,42,43 and column or data electrodes 31,32,33. These pixels 11 are all coupled to a common electrode 6, and each pixel 11 is coupled to its own pixel electrode 5. The electrophoretic display unit 1 further comprises a row driver 40 coupled to the row electrodes 41,42,43 and a column driver 30 coupled to the column electrodes 31,32,33 and comprises an active switching element 12 for each pixel 11. The electrophoretic display unit 1 is driven by these active switching elements 12 (in this example (thin-film) transistors). The row driver 40 consecutively selects the row electrodes 41,42,43, while the column driver 30 provides data signals to the column electrode 31,32,33. Preferably, a controller 20 first processes incoming data arriving via input 21 and then generates the data signals. Mutual synchronization between the column driver 30 and the row driver 40 takes place via drive lines 23 and 24. Selection signals from the row driver 40 select the pixel electrodes 5 via the transistors 12 of which the drain electrodes are electrically coupled to the pixel electrodes 5 and of which the gate electrodes are electrically coupled to the row electrodes 41,42,43 and of which the source electrodes are electrically coupled to the column electrodes 31,32,33. A data signal present at the column electrode 31,32,33 is simultaneously transferred to the pixel electrodes 5 of the pixels 11 coupled to the drain electrode of the transistors 12. Instead of transistors,

other switching elements can be used, such as diodes, MIMs, etc. The data signals and the selection signals together form (parts of) driving signals.

Incoming data, such as image information receivable via input 21 is processed by controller 20. Thereto, controller 20 detects an arrival of new image information about a new image and in response starts the processing of the image information received. This processing of image information may comprise the loading of the new image information, the comparing of previous images stored in a memory of controller 20 and the new image, the interaction with temperature sensors, the accessing of memories containing look-up tables of drive waveforms etc. Finally, controller 20 detects when this processing of the image information is ready.

Then, controller 20 generates the data signals to be supplied to column driver 30 via drive lines 23 and generates the selection signals to be supplied to row driver 40 via drive lines 24. These data signals comprise data-independent signals which are the same for all pixels 11 and data-dependent signals which may or may not vary per pixel 11. The data-independent signals comprise shaking pulses forming the preset pulses, with the data-dependent signals comprising one or more reset pulses and one or more driving pulses. These shaking pulses comprise pulses representing energy which is sufficient to release the electrophoretic particles 8,9 from a static state at one of the two electrodes 5,6, but which is too low to allow the particles 8,9 to reach the other one of the electrodes 5,6. Because of the reduced dependency on the history, the optical response to identical data will be substantially equal, regardless of the history of the pixels. So, the shaking pulses reduce the dependency of the optical response of the electrophoretic display unit on the history of the pixels. The reset pulse precedes the driving pulse to further improve the optical response, by defining a flexible starting point for the driving pulse. This starting point may be a black or white level, to be selected in dependence on and closest to the gray value defined by the following driving pulse. Alternatively, the reset pulse may form part of the data-independent signals and may precede the driving pulse to further improve the optical response of the electrophoretic display unit, by defining a fixed starting point for the driving pulse. This starting point may be a fixed black or fixed white level.

In Fig. 3, a waveform representing voltages across a pixel 11 as a function of time t is shown for driving an electrophoretic display unit 1. The waveform is generated using the data signals supplied via the column driver 30. The waveform comprises shaking pulses Sh, followed by a combination of reset pulses R and a combination of driving pulses Dr. For example, for an electrophoretic display unit with four gray levels, sixteen different

waveforms are stored in a memory, like, for example, a look-up table memory etc. forming part of and/or coupled to controller 20. In response to data received via input 21, controller 20 selects a waveform for one or more pixels 11, and supplies the corresponding selection signals and data signals via the corresponding drivers 30,40 to the corresponding transistors 12 and the corresponding one or more pixels 11.

A frame period corresponds to a time-interval used for driving all pixels 11 in the electrophoretic display unit 1 once, by driving each row one after the other and by driving all columns once per row. For supplying data-independent signals to the pixels 11 during frames, column driver 30 is controlled in such a way by controller 20 that all pixels 11 in a row receive these data-independent signals simultaneously. This is done row by row, with controller 20 controlling row driver 40 in such a way that the rows are selected one after the other (all transistors 12 in the selected row are brought into a conducting state). For supplying data-dependent signals to the pixels 11 during frames, controller 20 controls row driver 40 in such a way that a first row is selected (all transistors 12 in this row are brought into a conducting state), after which column driver 30 is controlled in such a way by controller 20 that the pixels 11 in this row receive these data-dependent signals simultaneously via their transistors 12. Then a next row is selected by controller 20 etc.

The voltage levels of a pixel 11 shown in Fig. 3 require, per row, a row driving action for supplying the row driving signal (the selection signal) to the row for selecting (driving) this row, and a column driving action for supplying the data pulse to the pixel.

During a first set of frames, the shaking pulses Sh are supplied to the pixels 11, with each shaking pulse having a duration of one frame period. The first shaking pulse, for example, has a positive amplitude, the second one a negative amplitude, and the third one a positive amplitude etc. (alternating amplitudes), and therefore these shaking pulses do not change the gray value displayed by the pixel 11, as long as the frame period is relatively short.

During a second set of frames comprising one or more frames periods, the combination of reset pulses R is supplied, further to be discussed below. During a third set of frames comprising one or more frames periods, the combination of driving pulses Dr is supplied, with the combination of driving pulses Dr either having a duration of zero frame periods and in fact being a pulse having a zero amplitude or having a duration of one, two to, for example, fifteen frame periods. Thereby, a driving pulse Dr having a duration of zero frame periods , for example, corresponds with the pixel 11 displaying full black (in case the pixel 11 already displayed full black; in case of displaying a certain gray value, this gray

value remains unchanged when being driven with a driving pulse having a duration of zero frame periods, or, formulated differently, when being driven with a pulse having a zero amplitude). The combination of driving pulses Dr having a duration of fifteen frame periods comprises fifteen subsequent pulses and, for example, corresponds with the pixel 11 displaying full white. The combination of driving pulses Dr having a duration of one to fourteen frame periods comprises one to fourteen subsequent pulses, which, for example, corresponds with the pixel 11 displaying one of a limited number of gray values between full black and full white.

The reset pulses R precede the driving pulses Dr to further improve the optical response of the electrophoretic display unit 1, by defining a fixed starting point (fixed black or fixed white) for the driving pulses Dr. Alternatively, reset pulses R precede the driving pulses Dr to further improve the optical response of the electrophoretic display unit, by defining a flexible starting point (black or white, to be selected in dependence of and closest to the gray value to be defined by the following driving pulses) for the driving pulses Dr.

As all frames have the same fixed duration, the driving of the prior art electrophoretic display unit 1 is highly inflexible. The number of gray values is limited, and cannot be increased, with the difference between two subsequent gray values being rather large.

Fig. 4 shows a first data-dependent signal Dr_1 and a second data-dependent signal Dr_2 as a function of a time t according to the invention each comprising a first frame period of 20 msec. and a second frame period of 30 msec. The first data-dependent signal Dr_1 consists of a first section having a duration of 20 msec. and a negative amplitude and a second section having a duration of 30 msec. and a positive amplitude. The net effect of the first data-dependent signal Dr_1 is equivalent to a pulse having a duration of 10 msec. and a positive amplitude, as illustrated by the small pulse filled with waves. The second data-dependent signal Dr_2 comprises next to a positive section during the first frame and a negative section during the second frame a third frame period of 20 msec. with a positive amplitude. The net effect of the second data-dependent signal Dr_2 is equivalent to a pulse having a duration of 10 msec. and a positive amplitude, as illustrated by the small pulse filled with waves. So, the net effect of the data-dependent signal Dr_1 and Dr_2 is equivalent as each one of them has the same net duration and amplitude. However, data-dependent signal Dr_1 allows a lower number of switching actions and a higher driving speed. Furthermore, this example illustrates that net pulses of 10 msec. can be provided, although the smallest frame period applied, is 20 msec.

These net pulses enable a possible increase of the number of possible gray values as well as smaller steps of subsequent gray values. Desired gray values are generated by a combination of frames with a positive and/or a negative frame period. During frames which are not selected for driving a pixel, this pixel 11 keeps its gray value due to its bi-stable character.

A frame period may be extended by delaying a start of a subsequent frame period. Controller 20 comprises and/or is coupled to a memory (not shown) like, for example, a look-up table memory for storing a number of data-dependent signal Dr_1,Dr_2 each corresponding to a gray level to be generated. For each data-dependent signal comprising a combination of driving pulses, information is stored about which frame periods to select for providing the data-dependent signal to be supplied to a pixel 11. Of course, this information can also be stored per combination of reset pulses, to increase the number of possible gray values for the reset pulses.

Fig. 5 shows a sequence of frame periods according to the invention comprising five different frames F_1, F_2, F_3, F_4 and F_5 with different frame period durations of 20 msec., 24 msec., 28 msec., 32 msec., and 36 msec. respectively. Twenty different data-dependent signals A-T each comprising one or more sections are shown, constructed via selections of these different frames and having net durations of 4, 8, 12 - 80 msec. respectively.

Data-dependent signal A has a net duration of 4 msec. as the signal comprises a first part with a positive amplitude supplied during F_2 and a second part with a negative amplitude supplied during F_1. In a short notation, the net duration of $A = F_2 - F_1$. The net durations of the data-dependent signals B-T are as follows. $B = F_3 - F_1$. $C = F_4 - F_1$. $D = F_5 - F_1$. $E = F_1$. $F= F_2$. $G = F_3$. $H = F_4$. $I = F_5$. $J = F_1 + F_1$. $K = F_1 + F_2$. $L = F_1 + F_3$. $M = F_2 + F_3$. $N = F_2 + F_4$. $O = F_3 + F_4$. $P = F_3 + F_5$. $Q = F_4 + F_5$. $R = F_1 + F_2 + F_3$. $S = F_1 + F_2 + F_4$. $T = F_1 + F_3 + F_4$ etc. Of course, many alternatives are possible. As can be clearly derived from Fig. 5, by creating a sequence of frames periods, with different frame periods in the sequence having different frame period durations, the net data-dependent signals can be shorter than the shortest frame period duration F_1 of an electrophoretic display unit 1, allowing for smaller values than in prior art embodiments. This enables a more accurate reproduction of gray levels.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any

reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

The invention is based upon an insight, inter alia, that prior art with fixed frame periods results in a relatively inflexible driving, and is based upon a basic idea, inter alia, that selections of (combinations of) different frame periods with different frame period durations make the driving more flexible.

The invention solves the problem, inter alia, by providing an electrophoretic display unit with a relatively flexible driving, and is advantageous, inter alia, in that the number of possible gray values is increased and in that the gray values can be generated more accurately.

CLAIMS:

1. An electrophoretic display unit (1) comprising:

- an electrophoretic display panel (DP) comprising a pixel (11);
- a controller (20) for generating a driving signal in dependence of an input image by selecting frame periods from a sequence of frame periods for providing pulses to the pixel (11), at least two frame periods of the sequence of frame periods having a different frame period duration; and
- drivers (30,40) for, in response to the driving signal, providing the pulses to the pixel (11).

2. An electrophoretic display unit (1) as claimed in claim 1, wherein the controller (20) is arranged to delay a start of a frame period, thereby adapting a frame period duration of a preceding frame period.

3. An electrophoretic display unit (1) as claimed in claim 1, wherein the drivers (30,40) are arranged to supply pulses with a positive amplitude and with a negative amplitude.

4. An electrophoretic display unit (1) as claimed in claim 1, further comprising a memory coupled to the controller (20) for storing information about the frame periods to be selected for the driving signal.

5. An electrophoretic display unit (1) as claimed in claim 4, wherein the driving signal comprises a column driving signal and a row driving signal for providing

- shaking pulses (Sh);
- one or more reset pulses (R); and
- one or more driving pulse (Dr),
- with the information being stored per combination of driving pulses (Dr).

6. An electrophoretic display unit (1) as claimed in claim 4, wherein the driving signal comprises a column driving signal and a row driving signal for providing:

- shaking pulses (Sh);
- one or more reset pulses (R); and
- one or more driving pulses (Dr),
- with the information being stored per combination of reset pulses (R).

7. A display device comprising an electrophoretic display unit (1) as claimed in claim 1; and a medium for storing information to be displayed on the display unit (1).

8. A method for driving an electrophoretic display unit (1) which comprises an electrophoretic display panel comprising a pixel (11), the method comprising the steps of:

- generating a driving signal in dependence of an input image by selecting frame periods from a sequence of frame periods for providing pulses to the pixel (11), at least two frame periods of the sequence of frame periods having a different frame period duration; and
- in response to the driving signal, providing the pulses to the pixel (11).

9. A computer program product for driving an electrophoretic display unit (1) which comprises an electrophoretic display panel comprising a pixel (11), the computer program product comprising the functions of:

- generating a driving signal in dependence of an input image by selecting frame periods from a sequence of frame periods for providing pulses to the pixel (11), at least two frame periods of the sequence of frame periods having a different frame period duration; and
- in response to the driving signal, providing the pulses to the pixel (11).

ABSTRACT:

Electrophoretic display units (1) are driven more flexibly by creating sequences of frame periods in which at least two frame periods of the sequence of frame periods have a different frame period duration and by selecting frame periods from a sequence of frame periods for providing driving pulses to the pixels (11). The number of possible gray values is increased, and the gray values can be generated more accurately. During the rest of the frame periods not chosen for driving the pixel (11), this pixel (11) keeps its gray value due to the bi-stable character. A frame period duration of a frame period is adapted by delaying a start of a next frame period. By supplying data-dependent signals having sections with a positive amplitude and with a negative amplitude, the net driving result is the difference between the sections with the positive and negative amplitudes, to further increase the number of possible gray values.

Fig. 4

Display device

The invention relates to a display device as defined in the pre-characterizing part of claim 1.

Display devices of this type are used in, for example, monitors, laptop computers, personal digital assistants (PDAs), mobile telephones and electronic books.

A display device of the type mentioned in the opening paragraph is known from international patent application WO 99/53373. This patent application discloses an electronic ink display comprising two substrates, one of which is transparent and the other substrate is provided with electrodes arranged in rows and columns. A crossing between a row and a column electrode is associated with a display element. The display element is coupled to the column electrode via a thin-film transistor (TFT), the gate of which is coupled to the row electrode. This arrangement of display elements, TFT transistors and row and column electrodes jointly forms an active matrix. Furthermore, the display element comprises a pixel electrode. A row driver selects a row of display elements and the column driver supplies a data signal to the selected row of display elements via the column electrodes and the TFT transistors. The data signal corresponds to graphic data to be displayed.

Furthermore, an electronic ink is provided between the pixel electrode and a common electrode provided on the transparent substrate. The electronic ink comprises multiple microcapsules of about 10 to 50 microns. Each microcapsule comprises positively charged white particles and negatively charged black particles suspended in a fluid. When a negative field is applied to the common electrode, the white particles move to the side of the microcapsule directed to the transparent substrate, and the display element becomes visible to a viewer. Simultaneously, the black particles move to the pixel electrode at the opposite side of the microcapsule where they are hidden from the viewer. By applying a positive field to the common electrode, the black particles move to the common electrode at the side of the microcapsule directed to the transparent substrate, and the display element appears dark to a viewer. When the electric field is removed, the display device remains in the acquired state and exhibits a bi-stable character.

Grey scales can be created in the display device by controlling the amount of particles that move to the counter electrode at the top of the microcapsules. For example, the energy of the positive or negative electric field, defined as the product of field strength and time of application, controls the amount of particles moving to the top of the microcapsules.

The known display devices have a so-called dwell time. The dwell time is defined as the interval between a previous image update and a new image update.

A disadvantage of the present display is that it exhibits an underdrive effect, which leads to inaccurate grey scale reproduction. This underdrive effect occurs, for example, when an initial state of the display device is black and the display is periodically switched between the white and the black state. For example, after a dwell time of several seconds, the display device is switched to white by applying a negative field for an interval of 200ms. In a subsequent interval, no electric field is applied for 200ms and the display remains white, and in the next interval a positive field is applied for 200 ms and the display is switched to black. The brightness of the display as a response of the first pulse of the series is below the desired maximum brightness, which can be reproduced several pulses later.

It is an object of the invention to provide a display device of the type mentioned in the opening paragraph which has an improved reproduction of grey scales.

To achieve this object, a first aspect of the invention provides a display device as defined in claim 1.

The invention is based on the recognition that the optical response depends on the history of the display element. The inventors have observed that when a preset signal is supplied before the drive signal to the pixel electrode, which preset signal comprises a pulse representing an energy which is sufficient to release the electrophoretic particle from a static state at one of the two electrodes, but is too low to reach the other one of the electrodes, the underdrive effect is reduced. Because of the reduced underdrive effect, the optical response to an identical data signal will be substantially equal, regardless of the history of the display device and in particular its dwell time. The underlying mechanism can be explained by the fact that, after the display device is switched to a predetermined state, e.g. a black state, the electrophoretic particles come to a static state, when a subsequent switching to the white state takes place, in which the momentum of the particles is low because their starting speed is close to zero. This results in a long switching time. The application of the preset pulses increases the momentum of the electrophoretic particles and thus reduces the switching time.

A further advantage is that the application of the preset pulses significantly reduces a prior history of the electronic ink, whereas, in contrast, conventional electronic ink display devices require massive signal processing circuits for generating data pulses of a new frame, storage of several previous frames and a large look-up table.

Such a preset pulse may have a duration of one order of magnitude less than the time interval between two subsequent image updates. An image update takes place when the image information of the display device is renewed or refreshed.

Further advantageous embodiments of the invention are defined in the dependent claims.

In an embodiment as defined in claim 3, the power dissipation of the display device can be minimised by applying just a single preset pulse.

In an embodiment as defined in claim 4, a preset signal consisting of an even number of preset pulses of opposite polarity can be generated for minimising the DC component and the visibility of the preset pulses of the display device. Two preset pulses, one with a positive polarity and one with a negative polarity will minimize the power dissipation of the display device in this mode of operation.

In an embodiment as defined in claim 5, the electrodes are arranged to form a passive matrix display.

In an embodiment as defined in claim 6, the display device is provided with an active matrix addressing to provide the data signals to the pixel electrodes of the display elements.

In an embodiment as defined in claim 7, the display elements are interconnected in two or more groups, wherein preset pulses having a different polarity are supplied to the different parts of the screen. For example, when in a single frame addressing period the preset pulses are applied with a positive polarity to all even rows and with a negative polarity to all odd rows, adjacent rows of the display device will appear alternately brighter and darker, and in the subsequent frame addressing period the positive and negative polarities of the preset pulses are inverted, in which the perceptual appearance will then hardly be affected, as the eye integrates these short brightness fluctuations both across the display (spatial integration) and on subsequent frames (temporal averaging). This principle is similar to the line inversion principle in methods of driving liquid crystal displays with reduced flicker.

In an embodiment as defined in claim 8, the preset signals are generated in the second driving means and applied to the pixel electrodes simultaneously by selecting, for

example, all even rows followed by all odd rows at a time by the first driving means. This embodiment requires no additional electronics on the substrates.

In an embodiment as defined in claim 9, the preset signals are applied directly via the counter electrode to the pixel electrode. An advantage of this arrangement is that the power consumption is lower because the capacitance involved in this case is lower than in a case where the row or column electrodes are addressed.

In an embodiment as defined in claim 10, the counter electrode is divided into several portions, in order to reduce the visibility of the preset pulses.

In an embodiment as defined in claim 11, the pixel electrode is coupled via a first additional capacitive element. The voltage pulses on the pixel electrode can now be defined as the ratio of a pixel capacitance and the first additional capacitive element. The pixel capacitance is the intrinsic capacitance of the material between the pixel electrode and the transparent substrate. Particularly in combination with an encapsulated electrophoretic material as supplied by E-Ink Corporation, this embodiment may be advantageous because, in case the first additional capacitive element is selected to have a large value compared to the pixel capacitance, the preset signal will substantially be transmitted to the pixel electrode, which reduces the power consumption.

Furthermore, the pixel capacitance will not vary significantly with the different applied grey levels. Thus, the preset pulse on the pixel electrode will be substantially equal for all display elements, irrespective of the applied grey levels.

In an embodiment as defined in claim 12, the pixel element is coupled to the control means via a further switching element. The further switching elements allow a division of the display elements into two or more groups.

In an embodiment as defined in claim 15, the grey scale reproduction of the display device can be further improved. Storing previous states and the current state of the display element and determining the drive signal in dependence upon the stored previous states, the current state and the new state of the display element improves the grey scale reproduction. In order to determine the drive signal, the processing means can be provided with a look-up table whose entries correspond to the previous state and the new state of the display elements.

In an embodiment as defined in claim 17, the grey scale reproduction can be further improved by incorporating a temperature sensor and a temperature compensation to correct the drive signal for the actual operating temperature of the display device.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

In the drawings:

Fig.1 is a diagrammatic cross-section of a portion of a display device,

Fig.2 is an equivalent circuit diagram of a portion of a display device,

Figs.3 and 4 show drive signals and internal signals of the display device,

Fig.5 shows an optical response of a data signal,

Fig. 6 shows an optical response of a preset signal and a data signal,

Fig. 7 shows preset signals for pixel electrodes for two adjacent rows consisting of 6 pulses of opposite polarities,

Fig 8 shows an example of a counter electrode comprising interdigitized comb structures,

Fig. 9 shows an equivalent circuit of a display element with two TFTs,

Fig. 10 shows a display device with a state memory,

Fig. 11 shows an integrated sequence of preset pulses and drive signals,

Fig. 12 shows a histogram of a display device with a state memory for two previous states, and

Fig. 13 shows a histogram of a display device with a state memory for two previous states and a drive signal preceded by four preset pulses for each transition.

The Figures are schematic and not drawn to scale, and, in general, like reference numerals refer to like parts.

Fig. 1 is a diagrammatic cross-section of a portion of an electrophoretic display device 1, for example of the size of a few display elements, comprising a base substrate 2, an electrophoretic film with an electronic ink which is present between two transparent substrates 3,4 of, for example, polyethylene. One of the substrates 3 is provided with transparent picture electrodes 5 and the other substrate 4 is provided with a transparent counter electrode 6. The electronic ink comprises multiple microcapsules 7 of about 10 to 50 microns. Each microcapsule 7 comprises positively charged white particles 8 and negatively charged black particles 9 suspended in a fluid 10. When a negative field is applied to the counter electrode 6, the white particles 8 move to the side of the microcapsule 7 directed to the counter electrode 6, and the display element becomes visible to a viewer. Simultaneously,

the black particles 9 move to the opposite side of the microcapsule 7 where they are hidden from the viewer. By applying a positive field to the counter electrodes 6, the black particles 9 move to the side of the microcapsule 7 directed to the counter electrode 6, and the display element appears dark to a viewer (not shown). When the electric field is removed, the particles 7 remain in the acquired state and the display exhibits a bi-stable character and consumes substantially no power.

Fig. 2 is an equivalent circuit diagram of a picture display device 1 comprising an electrophoretic film laminated on a base substrate 2 provided with active switching elements, a row driver 16 and a column driver 10. Preferably, a counter electrode 6 is provided on the film comprising the encapsulated electrophoretic ink, but could be alternatively provided on a base substrate in the case of operation with in-plane electric fields. The display device 1 is driven by active switching elements, in this example thin-film transistors 19. It comprises a matrix of display elements at the area of crossings of row or selection electrodes 17 and column or data electrodes 11. The row driver 16 consecutively selects the row electrodes 17, while a column driver 10 provides a data signal to the column electrode 11. Preferably, a processor 15 first processes incoming data 13 into the data signals. Mutual synchronisation between the column driver 10 and the row driver 16 takes place via drive lines 12. Select signals from the row driver 16 select the pixel electrodes 22 via the thin-film transistors 19 whose gate electrodes 20 are electrically connected to the row electrodes 17 and the source electrodes 21 are electrically connected to the column electrodes 17. A data signal present at the column electrode 17 is transferred to the pixel electrode 22 of the display element coupled to the drain electrode via the TFT. In the embodiment, the display device of Fig.1 also comprises an additional capacitor 23 at the location of each display element 18. In this embodiment, the additional capacitor 23 is connected to one or more storage capacitor lines 24. Instead of TFTs, other switching elements can be used, such as diodes, MIMs, etc.

Figs. 3 and 4 show drive signals of a conventional display device. At the instant t0, a row electrode 17 is energized by means of a selection signal Vsel (Fig.1), while simultaneously data signals Vd are supplied to the column electrodes 11. After a line selection time tL has elapsed, a subsequent row electrode 17 is selected at the instant t1, etc. After some time, for example, a field time or frame time, usually 16.7 msec or 20 msec, said row electrode 17 is energized again at instant t2 by means of a selection signal Vsel, while simultaneously the data signals Vd are presented to the column electrode 11, in the case of an unchanged picture. After a selection time tL has elapsed, the next row electrode is selected at

the instant t3. This is repeated from instant t4. Because of the bistable character of the display device, the electrophoretic particles remain in their selected state and the repetition of data signals can be halted after several frame times when the desired grey level is obtained. Usually, the image update time is several frames.

Fig. 5 shows a first signal 51 representing an optical response of a display element of the display device of Fig.2 on a data signal 50 comprising pulses of alternating polarity after a dwell period of several seconds. In Fig. 5, the optical response 51 is indicated by ---- and the data signal by____. Each pulse 52 of the data signal 50 has a duration of 200 ms and a voltage with an alternating polarity of plus and minus 15 V. Fig 5 shows that the optical response 51 after the first negative pulse 52 is not a desired grey level, which is obtained only after the third or fourth negative pulse.

In order to improve the accuracy of the desired grey level with the data signal, the processor 15 generates a single preset pulse or a series of preset pulses before the data pulses of a subsequent refresh field, where the pulse time is typically 5 to 10 times less than the interval between an image update and a subsequent image update. If the interval between two image updates is 200 ms, the duration of a preset pulse is typically 20 ms.

Fig. 6 shows the optical response of a data signal 60 of the display device of Fig.2 as a response of a series of 12 preset pulses of 20 ms and data pulses of 200 ms having a voltage of alternating polarity of plus and minus 15 V. In Fig. 5, the optical response 51 is indicated by ---- , the improved optical response 61 by -.-.-.-.- and the data signal by____.The series of preset pulses consists of 12 pulses of alternating polarity. The voltage of each pulse is plus or minus 15 V. Fig. 6 shows a significant increase of the grey scale accuracy, the optical response 61 is substantially at the same level as the optical response after the fourth data pulse 55. However, some flicker introduced by the preset pulses may become visible, see optical response 56. In order to reduce the visibility of this flicker, the processor 15 and the row driver 16 can be arranged in such a way that the row electrodes 17 associated with display elements are interconnected in two groups, and the processor 15 and the column driver 10 are arranged to execute an inversion scheme by generating a first preset signal having a first phase to the first group of display elements and a second reset signal having a second phase to the second group of display elements, wherein the second phase is opposite to the first phase. Alternatively, multiple groups can be defined, for which reset pulses are supplied with different phases. For example, the row electrodes 17 can be interconnected in two groups, one group of the even rows and one group of the odd rows, with the processor generating a first preset signal consisting of six preset pulses with an alternating polarity of

plus and minus 15 V, starting with a negative pulse to the display elements of the even rows, and a second preset signal consisting of six preset pulses of alternating polarity of plus and minus 15 V, starting with a positive pulse to display elements of the odd rows.

Fig 7 shows two graphs which are indicative of an inversion scheme. A first graph 71 relates to a first preset signal consisting of 6 preset pulses of 20 ms supplied to a display element of an even row n, and a second graph 73 relates to a second preset signal consisting of 6 preset pulses of 20 ms supplied to a display element of an odd row n+1, wherein the phase of the second preset signal is opposite to the phase of the first preset signal. The voltage of the pulse alternates between plus and minus 15 V.

Instead of the series of preset pulses applied to two or more different groups of rows, the display elements can be divided into two groups of columns, for example, one group of even columns and one group of odd columns, wherein the processor 15 executes an inversion scheme by generating a first preset signal consisting of six preset pulses of alternating polarity of plus and minus 15 V, starting with a negative pulse to the display elements of the even columns, and a second preset signal consisting of six preset pulses of alternating polarity of plus and minus 15 V, starting with a positive pulse to the display elements of the odd columns. Here, all rows can be selected simultaneously. In further embodiments, inversion schemes as discussed above can be simultaneously supplied to both rows and columns to generate a so-called dot-inversion scheme, which still further reduces optical flicker.

In a further embodiment, the counter electrode 80 is shaped as two interdigitized comb structures 81,83 as shown in Fig. 8 in order to reduce optical flicker. This kind of electrode is well known to the skilled person. The two counter electrodes 81,83 are coupled to two outputs 85,87 of the processor 15. Furthermore, the processor 15 is arranged to generate an inversion scheme by supplying a first preset signal consisting of six preset pulses of 20 ms and an alternating polarity of plus and minus 15 V, starting with a negative pulse to the first comb structure 81, and a second preset signal consisting of six preset pulses of 20 ms and an alternating polarity of plus and minus 15 V, starting with a positive pulse to the second comb structure 83, whilst maintaining the pixel electrode 23 at 0 V. After the preset pulses are supplied, the two comb structures 81,83 can be connected to each other before new data is supplied to the display device.

In a further embodiment, the preset pulses can be applied by the processor 15 via the additional storage capacitors 23 by charge sharing between the additional storage capacitor 23 and the pixel capacitance 18. In this embodiment, the storage capacitors on a

row of display elements are connected to each other via a storage capacitor line, and the row driver 16 is arranged to interconnect these storage capacitor lines to each other in two groups allowing inversion of the preset pulses across two groups, a first group related to even rows of display elements and a second group related to odd rows of display elements. In order to improve grey scale reproduction before new data is supplied to the display elements, the row driver executes an inversion scheme by generating a first preset signal consisting of 6 preset pulses of alternating polarity to the first group, and a second preset signal consisting of 6 preset pulses of alternating polarity to the second group, wherein the phase of the second signal is opposite to the phase of the first signal. After the preset pulses are supplied to the display elements, the storage capacitors can be grounded before the new data is supplied to the display elements.

In a further embodiment, the preset pulses can be applied directly to the pixel electrode 22 by the processor 15 via an additional thin-film transistor 90 coupled via its source 94 to a dedicated preset pulse line 95. The drain 92 is coupled to the pixel electrode 22. The gate 91 is coupled via a separate preset pulse addressing line 93 to the row driver 16. The addressing TFT 19 must be non-conducting by, for example, setting the row electrode 17 to 0 V.

When the preset signal is applied to all display elements simultaneously, flicker may occur. Therefore, preset signal inversion is applied by division of the additional thin-film transistors 90 into two groups, one group being connected to display elements of even rows and one group being connected to display elements of odd rows. Both groups of TFTs 90 are separately addressable and connected to the preset pulse lines 95. The processor 15 executes an inversion scheme by generating a first preset signal consisting of, for example, 6 preset pulses of 20 ms and a voltage 15 V of alternating polarity to the first group of TFTs 90 via the preset pulse line 95, and a second preset signal consisting of 6 preset pulses of 20 ms and a voltage of 15 V of alternating polarity to the second groups of TFTs 90, wherein the phase of the second signal is opposite to the phase of the first signal. Alternatively, a single set of TFTs addressable in the same period can be attached to two separate preset pulse lines with inverted pre set pulses.

After the preset signals are supplied to the TFTs 90, the TFTs are deactivated before new data is supplied via the column drivers 10.

Further power reductions are possible in the described embodiments by applying any of the well-known charge recycling techniques to the (inverted) preset pulse

sequences to reduce the power used to charge and discharge pixel electrodes during the preset pulse cycles.

In order to improve the grey-scale reproduction of the displayed image information, a conventional electrophoretic display device can be provided with memory means for storing various previous states and the current state of the display elements.

Fig. 10 shows a conventional electrophoretic display device 100 for displaying image information provided to the display device in a series of consecutive frames N-1,N, N+1. The display device has a similar arrangement as the device as shown in Fig. 2, extended with memory means, for example, a first RAM memory 101 and a second RAM memory 103 for storing a previous state of the display elements corresponding to a frame N-1 directly before a current frame N is displayed, and a current state of the display elements corresponding to the current frame N which is being displayed, respectively. Furthermore, processing means 15 are arranged to generate the drive signal 12 in dependence upon the stored previous state of the previous frame N-1, the stored current state of the display element corresponding to the current frame N being displayed and the new state of the display element corresponding to the new frame N+1 to be displayed. Preferably, the processing means 15 comprises a look-up table 105 which has address entries corresponding to one previous state of the display element, the current state of the display element and the new state of the display element, each state corresponding to a 4-bit number corresponding to a 16-level grey scale. These bits together form a 12-bit entry in the look-up table 105. Furthermore, the display device 100 may be provided with a digital temperature sensor 107 for sensing an operating temperature of the device and for providing a temperature compensation in order to reduce the temperature dependency of the grey value reproduction of the display device. To this end, the temperature sensor 107 generates, for example, a 4-bit number representing an actual operating temperature of the display device, and the entry of the look-up table 105 is extended with these further 4 bits. Now, the look-up table entry consists of 16 bits. These entries of the look-up table 105 point to a predetermined drive parameter of the drive signal for transition of a display element from a first grey value corresponding to a current state corresponding to frame N to a second grey value in a new state corresponding to frame N+1. The look-up table 105 can be realized in a ROM memory. The drive signal may consist of a pulse of fixed duration and varying amplitude, a pulse with a fixed amplitude, alternating polarity and a varying duration between two extreme values, and a hybrid drive signal wherein both the pulse length and the amplitude can be varied. For a pulse amplitude drive signal, this predetermined drive parameter indicates the amplitude of

the drive signal including the sign thereof. For a pulse time modulated drive signal, the predetermined drive parameter indicates the duration and sign of the pulse making up the drive signal. For a hybrid generation or pulse-shaped drive signal, the predetermined drive parameter indicates the amplitude and the length of portions making up the drive pulse. The predetermined drive parameter may be, for example, an 8-bit number. For each entry in the look-up table 105, the drive parameter is experimentally determined for a selected type of electronic ink for a corresponding grey level transition and different predetermined operating temperatures. The drive signal 12 is applied to the column driver 10.

Furthermore, the generation of the drive signal in this electrophoretic display device 100 can be combined with the preset pulses in order to further improve the reproduction of grey scales. To this end, the preset pulses are generated before the drive signal in accordance with the examples described above. For example, the preset pulses may consist of 4 pulses having a duration of 40 ms and an amplitude of 15 V and an alternating polarity.

Fig. 11 shows an integrated sequence of preset pulses 97 and 4 drive signals V(n), V(n+1),V(n+2), V(n+3).

A comparison of the grey value reproduction of a conventional electrophoretic display without preset pulses inserted before the drive signal and an electrophoretic display device with preset pulses inserted before each drive signal is given in Fig. 12 and Fig.13.

Fig. 12 shows a first histogram 120 of the brightness of a number of display elements of an electrophoretic display device comprising memories for two previous states of the display table and a look-up table. The brightnesses are measured after a transition from one of the 4 predetermined states corresponding to frame N to another of the 4 predetermined states corresponding to frame N+1. The previous states stored in the memories are a first previous state corresponding to a frame N-1, and a present state corresponding to a frame N. The first histogram shows the number of display elements having a brightness in L* as the result of a sequence of 1000 random transitions between 4 predetermined reflectance values, i.e. corresponding to 4 grey values of the drive signal with a dwell time of 2 seconds between two consecutive transitions. The maximum value of the brightness L* that can be obtained is 70. The minimal value of the brightness L* is 25. The brightness L* is defined as 116. $(\text{reflectance}/100)^{1/3}-16$, where the reflectance is a number between 0 and 100, 0 indicates no reflectance and 100 indicates absolute reflection.

In this conventional electrophoretic display device, no preset pulses are generated before the drive signal for a transition from one of the 4 predetermined grey values

to another one of the 4 predetermined grey values. As can be seen from Fig. 12, the grey scale reproduction is poor.

Fig. 13 shows a second histogram 130 of the brightness of a number of display elements of an electrophoretic display device comprising memories for two previous states and a look-up table wherein preset pulses are inserted before the drive signal for a transition from one of the 4 predetermined grey values to another one of the predetermined grey values.

The brightness is measured after a transition from one of the 4 predetermined states corresponding to frame N to another of the 4 predetermined states corresponding to frame N+1. The previous states stored in the memories are a first previous state corresponding to a frame N-1, and a current state corresponding to a frame N. The second histogram 130 shows the brightness in L* of a number of display elements as the result of a sequence of 1000 random transitions to 4 possible reflectance values, i.e. corresponding to 4 predetermined grey values of the drive signal with a dwell time of 2 seconds between two consecutive transitions. The preset pulse sequence consists of 4 pulses of a duration of 40 ms and an amplitude of 15 V and an alternating polarity. A part of this sequence is shown in Fig. 11.

Fig. 13 shows that, with the reduced width of the distributions corresponding to the 4 predetermined grey scales as compared with the width of the distributions of the histogram in Fig. 12, the grey scale reproduction has improved significantly, wherein the grey scale error is 1.5 L*.

It will be obvious that many variations are possible within the scope of the invention without departing from the scope of the appended claims.

CLAIMS:

1. A display device comprising electrophoretic particles, a display element comprising a pixel electrode and an associated counter electrode, between which a portion of the electrophoretic particles is present, and control means for supplying a drive signal to the electrodes to bring the display element to a predetermined optical state corresponding to the image information to be displayed, characterized in that control means are further arranged to supply a preset signal preceding the drive signal comprising a preset pulse representing an energy which is sufficient to release the electrophoretic particles at a first position near one of the two electrodes corresponding to a first optical state, but is too low to enable the particles to reach a second position near the other electrode corresponding to a second optical state.

2. A display device as claimed in claim 1, wherein the duration of the preset pulse is one order of magnitude less than a time interval between two subsequent image updates.

3. A display device as claimed in claim 1, wherein the control means are further arranged to generate the preset pulse with a negative or positive polarity, and the control means are further arranged to generate the drive signal comprising a pulse with a negative or positive polarity, wherein the polarity of the preset pulse is opposite to the polarity of the pulse of the data signal.

4. A display device as claimed in claim 3, wherein the control means are further arranged to generate an even number of preset pulses.

5. A display device as claimed in claim 1, wherein one of the electrodes comprises a data electrode and the other electrode comprises a selection electrode, and the control means further comprise first drive means for applying a selection signal to the selection electrodes and second drive means for applying a data signal to the data electrode.

6. A display device as claimed in claim 1, wherein the pixel electrode of the display element is coupled to a selection electrode or a data electrode via a switching element, and the control means further comprise first drive means for applying a selection signal to the selection electrodes and second drive means for applying a data signal to the data electrode.

7. A display device as claimed in claim 5 or 6, wherein selection electrodes associated with display elements are interconnected in two groups, and the control means are arranged to generate a first preset signal having a first phase to the first group and a second reset signal having a second phase opposite to the first phase to the second group.

8. A display device as claimed in claim 5 or 6, wherein the second drive means are arranged to generate the preset signal.

9. A display device as claimed in claim 5 or 6, wherein the pixel electrode is coupled to the control means for generating the reset signal via the counter electrode.

10. A display device as claimed in claim 9, wherein the counter electrode is divided into two portions, and wherein each portion is associated with a set of display elements connected via a selection electrode.

11. A display device as claimed in claim 6, wherein the pixel electrode is coupled via a first additional capacitive element to the control means for receiving the preset signal.

12. A display device as claimed in claim 6, wherein the pixel electrode is coupled to the control means via a further switching element.

13. A display device as claimed in claim 1, wherein the display comprises two substrates, one of which is transparent, and the electrophoretic particles are present between the two substrates.

14. A display device as claimed in claim 1, wherein the electrophoretic material is an encapsulated electrophoretic material.

15. A display device as claimed in claim 1, wherein the image information is received in consecutive frames N-1,N and the display device further comprises memory means for storing a previous display state of the display elements corresponding to a frame N-1 directly before a new frame N to be displayed, and the processing means are further arranged to generate the drive signal in dependence upon the stored previous states and the new state of the display element corresponding to the new frame to be displayed.

16. A display device as claimed in claim 1, wherein the image information is received in consecutive frames N-1,N, N+1 and the display device further comprises memory means for storing a previous display state of the display elements corresponding to a frame N-1 directly before a current frame N is displayed and the current display state of the frame N is displayed, and the processing means are further arranged to generate the drive signal in dependence upon the stored previous state, the current state and the new state of the display element corresponding to the new frame N+1 to be displayed.

17. A display device as claimed in claim 1, wherein the display device is provided with a temperature sensor for sensing an operating temperature of the display device and a temperature compensating circuit for generating a drive signal in dependence upon a desired grey value and operating temperature.

ABSTRACT:

The invention relates to a display device comprising electrophoretic particles, a display element comprising a pixel electrode and an associated counter electrode, between which a portion of the electrophoretic particles is present, and a controller for supplying a drive signal to the electrodes to bring the display element to a predetermined black or white state, corresponding to the image information to be displayed. In order to improve the refresh time of the display, the controller is further arranged to supply a preset signal preceding the drive signal comprising a preset pulse representing an energy which is sufficient to release the electrophoretic particles at a first position near one of the two electrodes corresponding to a black state, but is too low to enable the particles to reach a second position near the other electrode corresponding to a white state.

Fig. 6

CLAIMS:

1. A display device (1) comprising electrophoretic particles (8, 9), a display element (18) comprising a pixel electrode (5) and an associated counter electrode (6), between which a portion of the electrophoretic particles (8) is present, and control means (15) for supplying a drive signal to the electrodes to bring the display element to a predetermined optical state corresponding to the image information to be displayed, characterized in that control means are further arranged to supply a preset signal (53, 71, 72; 97) preceding the drive signal (Vn) comprising a preset pulse representing an energy which is sufficient to release the electrophoretic particles at a first position near one of the two electrodes (5, 6) corresponding to a first optical state, but is too low to enable the particles (8, 9) to reach a second position near the other electrode (5, 6) corresponding to a second optical state.

2. A display device as claimed in claim 1, wherein the duration of the preset pulse is one order of magnitude less than a time interval between two subsequent image updates.

3. A display device as claimed in claim 1, wherein the control means (15) are further arranged to generate the preset pulse with a negative or positive polarity, and the control means are further arranged to generate the drive signal comprising a pulse with a negative or positive polarity, wherein the polarity of the preset pulse is opposite to the polarity of the pulse of the data signal.

4. A display device as claimed in claim 3, wherein the control means are further arranged to generate an even number of preset pulses.

5. A display device as claimed in claim 1, wherein one of the electrodes (5, 6) comprises a data electrode (11) and the other electrode (5, 6) comprises a selection electrode (17), and the control means further comprise first drive means (16) for applying a selection signal to the selection electrodes (17) and second drive means (10) for applying a data signal to the data electrode (11).

6. A display device as claimed in claim 1, wherein the pixel electrode (22) of the display element (18) is coupled to a selection electrode (11) or a data electrode (17) via a switching element (19), and the control means (15) further comprise first drive means (11) for applying a selection signal to the selection electrodes and second drive means (10) for applying a data signal to the data electrode (11).

7. A display device as claimed in claim 5 or 6, wherein selection electrodes (17) associated with display elements (18) are interconnected in two groups (81, 83), and the control means (15) are arranged to generate a first preset signal having a first phase to the first group (81) and a second reset signal having a second phase opposite to the first phase to the second group (83).

8. A display device as claimed in claim 5 or 6, wherein the second drive means (10) are arranged to generate the preset signal.

9. A display device as claimed in claim 5 or 6, wherein the pixel electrode (22) is coupled to the control means for generating the reset signal via the counter electrode (6).

10. A display device as claimed in claim 9, wherein the counter electrode (6) is divided into two portions, and wherein each portion is associated with a set of display elements connected via a selection electrode.

11. A display device as claimed in claim 6, wherein the pixel electrode (22) is coupled via a first additional capacitive element (23) to the control means (15) for receiving the preset signal.

12. A display device as claimed in claim 6, wherein the pixel electrode (22) is coupled to the control means (15) via a further switching element (90).

13. A display device as claimed in claim 1, wherein the display comprises two substrates (3, 4), one (4) of which is transparent, and the electrophoretic particles are present between the two substrates.

14. A display device as claimed in claim 1, wherein the electrophoretic material (8, 9) is an encapsulated electrophoretic material.

15. A display device as claimed in claim 1, wherein the image information is received in consecutive frames N-1,N and the display device further comprises memory means (101, 103) for storing a previous display state of the display elements corresponding to a frame N-1 directly before a new frame N to be displayed, and the processing means (15) are further arranged to generate the drive signal in dependence upon the stored previous states and the new state of the display element (18) corresponding to the new frame to be displayed.

16. A display device as claimed in claim 1, wherein the image information is received in consecutive frames N-1,N, N+1 and the display device further comprises memory means for storing a previous display state of the display elements corresponding to a frame N-1 directly before a current frame N is displayed and the current display state of the frame N is displayed, and the processing means (15) are further arranged to generate the drive signal in dependence upon the stored previous state, the current state and the new state of the display element corresponding to the new frame N+1 to be displayed.

17. A display device as claimed in claim 1, wherein the display device is provided with a temperature sensor (107) for sensing an operating temperature of the display device and a temperature compensating circuit (15) for generating a drive signal in dependence upon a desired grey value and operating temperature.

Electrophoretic display panel

The invention relates to an electrophoretic display panel for displaying a picture.

An embodiment of the electrophoretic display panel of the type mentioned in the opening paragraph is described in non-prepublished European Patent application 02078456.7 (PHNL020754).

In the described electrophoretic display panel, each pixel of the plurality of pixels has, during the display of the picture, an appearance determined by the position of the charged particles between the electrodes. The position of the particles depends on the potential difference as the particles migrate through the fluid as a consequence of the potential difference. The migration of the particles through the fluid also depends on the viscosity of the fluid. As the viscosity of the fluid is determined by the medium temperature, the position of the particles depends not only on the potential difference, but also on the medium temperature. The display panel comprises heating means and is thereby able to have a predetermined substantially constant medium temperature above ambient temperature. As a result, the display panel is able to have pixels with substantially reproducible appearances at the predetermined medium temperature. The heating means heat the medium to the predetermined medium temperature, which may be relatively highly power consuming, e.g. if the predetermined medium temperature is substantially higher than the ambient temperature. The predetermined medium temperature is chosen relatively high to be able to change the appearances of the pixels in a relatively short interval.

It is a drawback of the described display panel that it requires relatively high energy to obtain therewith pixels with substantially reproducible appearances independent of the ambient temperature.

It is an object of the invention to provide a display panel of the kind mentioned in the opening paragraph which is able to have pixels with substantially reproducible

appearances requiring relatively little energy independent of the ambient temperature.

To achieve this object, the display panel in accordance with the invention is specified in Claim 1.

The invention is based on the insight that, if the dependency of the appearances of the pixels on the medium temperature is compensated for by the potential differences, the appearances of the pixels are substantially reproducible. This dependency is compensated for by the potential differences without the need for heating means regulating the medium temperature. As relatively low power consuming electrical circuits can be used to perform the compensation, the appearances of the pixels are substantially reproducible requiring relatively little energy independent of the ambient temperature. As the drive means are able to receive the measured temperature indicative for the medium temperature from the temperature probe and to control the potential differences in dependence of the measured temperature, the display panel is able to have pixels with substantially reproducible appearances requiring relatively little energy independent of the ambient temperature. This is in contrast to the display panel described in non-prepublished European Patent application 02078456.7 (PHNL020754) which requires, due to the relatively high power consuming heating means, relatively high energy to have pixels with substantially reproducible appearances if the predetermined medium temperature is maintained at a substantially higher level than the ambient temperature. Furthermore, the prior art display panel does not have pixels with substantially reproducible appearances at an ambient temperature above the predetermined medium temperature, because the heating means are unable to cool the medium to the predetermined medium temperature.

In an embodiment the drive means are able to control the durations in dependence of the measured temperature. The durations are relatively short if the medium is able to change relatively fast between two appearances and relatively long if the medium is only able to change relatively slow between two appearances. For instance, as the medium at 60 °C is able to change faster between two appearances than at 20 °C, the durations at the higher temperature are shorter than the durations at the lower temperature.

In a modification of the last embodiment the drive means are able to control each duration to consist of a number of intervals of equal time period, the number being

determined by the picture to be displayed and the measured temperature, and the time period being constant. Then only the number of intervals has a different value if the measured temperature has changed.

In another modification of the last embodiment the drive means are able to control each duration to consist of a number of intervals of equal time period, the number being determined by the picture to be displayed and the time period being determined by the measured temperature. Then only the time period has a different value if the measured temperature has changed.

In another embodiment the drive means are able to control the levels in dependence of the measured temperature. The levels are relatively low if the medium is able to change relatively fast between two appearances and relatively high if the medium is only able to change relatively slow between two appearances. For instance, as the medium having a temperature of 60 °C is able to change faster between two appearances than the medium having a temperature of 20 °C, the levels at the higher temperature are shorter than the levels at the lower temperature.

If the first substrate comprises the first electrodes, and the second substrate comprises the second electrodes, the appearances of the pixels can relatively easy be changed compared to the display panel having one of the substrates comprising the first and the second electrode.

These and other aspects of the display panel of the invention will be further elucidated and described with reference to the drawings, in which:

Figure 1 shows diagrammatically a front view of a first embodiment of the display panel;

Figure 2 shows diagrammatically a cross-sectional view along II-II in Figure 1;

Figure 3 shows in a graphical form the relation between the measured temperature and the durations for the first embodiment; and

Figure 4 shows in a graphical form the relation between the measured temperature and the levels for a second embodiment.

In all the Figures corresponding parts are referenced to by the same reference numerals.

Figures 1 and 2 show the first embodiment of the display panel 1 having a second substrate 9 and a plurality of pixels 2. The pixels 2 are arranged along substantially straight lines in a two-dimensional structure. Other arrangements of the pixels 2 are also possible, e.g. a honeycomb arrangement. The display panel 1 has a first substrate 8 and a second opposed substrate 9. An electrophoretic medium 5 is present between the substrates 8,9. The electrophoretic medium 5 comprises for instance negatively charged black particles 6 in a white fluid. Electrophoretic media are known per se from e.g. US 5,961,804, US 6,120,839 and US 6,130,774 and can e.g. be obtained from E Ink Corporation. A first and a second electrode 3,4 are associated with each pixel 2. The electrodes 3,4 are able to receive a potential difference. In Figure 2 the first substrate 8 has for each pixel 2 a first electrode 3, and the second substrate 9 has for each pixel 2 a second electrode 4. When the charged particles 6 are positioned near the first electrode 3 due to a potential difference having a level of 15 Volts, the pixel 2 has a first appearance, i.e. white. When the charged particles 6 are positioned near the second electrode 4, due to a potential difference of opposite polarity, having a level of –15 Volts, the pixel 2 has a second appearance, i.e. black. A temperature probe 11, e.g. present on the surface of the first substrate 8 facing the medium, is able to measure a temperature indicative for the medium temperature. Furthermore, the drive means 100 are able to control the potential differences for displaying the picture, to receive the measured temperature from the temperature probe 11, and to control the potential differences in dependence of the measured temperature.

Figure 3 shows the relation between the measured temperature and the durations of the potential differences for the first embodiment. The levels of the potential differences are 15 Volts. The distance between the electrodes 3,4 is about 80 micrometer. The layer of electrophoretic medium 5 has a thickness of about 50 micrometer. Furthermore, a layer of polymer binder material having a thickness of about 30 micrometer is present between the electrodes 3,4. The line 'a' is related to a change in appearance of the pixel from black to white, denoted as transition B-W, and the line 'b' is related to a change in appearance of the pixel from dark gray to light gray, denoted as transition DG-LG. The durations decrease with increasing measured temperature. In the first embodiment the drive means 100 are able to control durations of the potential differences in dependence of the measured temperature according to Figure 3. Therefore, the dependency of the appearances of the pixels on the medium temperature is compensated for by the potential differences and the display panel 1 is able to have pixels 2 with substantially reproducible appearances

requiring relatively little energy independent of the ambient temperature. The relation between the measured temperature and the durations may be incorporated in the drive means 100 by means of a look-up-table. Furthermore, Figure 3 shows that the duration of the transition B-W is substantially proportional to the duration of the transition DG-LG. Therefore, in a variation of the first embodiment the drive means 100 are able to control each duration to consist of a number of intervals of equal time period, the number being determined by the picture to be displayed and the measured temperature, and the time period being constant. In another variation of the first embodiment the drive means 100 are able to control each duration to consist of a number of intervals of equal time period, the number being determined by the picture to be displayed and the time period being determined by the measured temperature.

Figure 4 shows the relation between the measured temperature and the levels of the potential differences for a second embodiment. The durations of the potential differences are 200 ms. The distance between the electrodes 3,4 is about 80 micrometer. The layer of electrophoretic medium 5 has a thickness of about 50 micrometer. Furthermore, a layer of polymer binder material having a thickness of about 30 micrometer is present between the electrodes 3,4. The relation is related to the transition B-W. The levels decrease with increasing measured temperature. In the second embodiment the drive means 100 are able to control levels of the potential differences in dependence of the measured temperature according to Figure 4. The relation between the measured temperature and the levels may be incorporated in the drive means 100 by means of a look-up-table.

CLAIMS:

1. An electrophoretic display panel for displaying a picture, comprising:
- a first and a second opposed substrate;
- an electrophoretic medium between the substrates, the electrophoretic medium comprising charged particles in a fluid;
- a plurality of pixels;
- a first and a second electrode associated with each pixel for receiving a potential difference having a duration and a level;
- drive means being able to control the potential differences for displaying the picture; and
- a temperature probe being able to measure a temperature indicative for a medium temperature, wherein
the drive means are further able to receive the measured temperature from the temperature probe and to control the potential differences in dependence of the measured temperature.

2. A display panel as claimed in claim 1 characterized in that the drive means are able to control the durations in dependence of the measured temperature.

3. A display panel as claimed in claim 2 characterized in that the drive means are able to control each duration to consist of a number of intervals of equal time period, the number being determined by the picture to be displayed and the measured temperature, and the time period being constant.

4. A display panel as claimed in claim 2 characterized in that the drive means are able to control each duration to consist of a number of intervals of equal time period, the number being determined by the picture to be displayed and the time period being determined by the measured temperature.

5. A display panel as claimed in claim 1 characterized in that the drive means are able to control the levels in dependence of the measured temperature.

6. A display panel as claimed in any one of the preceding claims, characterized in that the first substrate comprises the first electrodes, and the second substrate comprises the second electrodes.

ABSTRACT:

The electrophoretic display panel (1) for displaying a picture, has a first and a second opposed substrate (8,9), an electrophoretic medium (5) between the substrates (8,9), a plurality of pixels (2), a first and a second electrode (3,4) associated with each pixel (2), drive means (100) and a temperature probe (11). The electrophoretic medium (5) has charged particles (6) in a fluid. The first and the second electrode (3,4) are able to receive a potential difference having a duration and a level. The drive means (100) are able to control the potential differences for displaying the picture, and the temperature probe (11) is able to measure a temperature indicative for the medium temperature. For the display panel (1) to be able to have pixels (2) with substantially reproducible appearances requiring relatively little energy independent of the ambient temperature, the drive means (100) are able to receive the measured temperature from the temperature probe (11) and to control the potential differences in dependence of the measured temperature.

Fig. 2

CLAIMS (with reference numbers):

1. An electrophoretic display panel (1) for displaying a picture, comprising:
- a first and a second opposed substrate (8,9);
- an electrophoretic medium (5) between the substrates (8,9), the electrophoretic medium (5) comprising charged particles (6) in a fluid;
- a plurality of pixels (2);
- a first and a second electrode (3,4) associated with each pixel (2) for receiving a potential difference having a duration and a level;
- drive means (100) being able to control the potential differences for displaying the picture; and
- a temperature probe (11) being able to measure a temperature indicative for a medium temperature, wherein
the drive means (100) are further able to receive the measured temperature from the temperature probe (11) and to control the potential differences in dependence of the measured temperature.

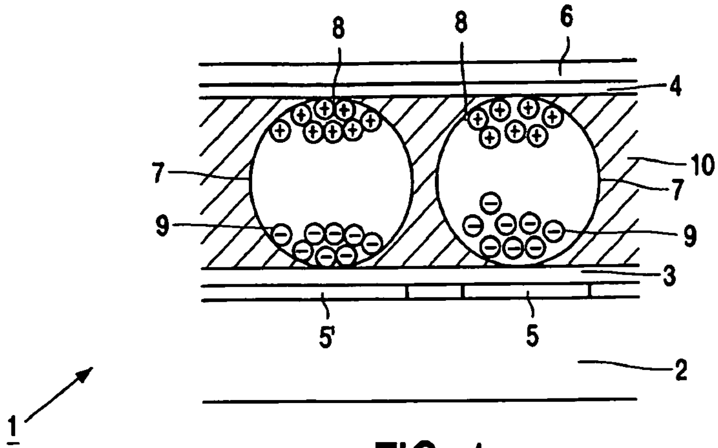
2. A display panel (1) as claimed in claim 1 characterized in that the drive means (100) are able to control the durations in dependence of the measured temperature.

3. A display panel (1) as claimed in claim 2 characterized in that the drive means (100) are able to control each duration to consist of a number of intervals of equal time period, the number being determined by the picture to be displayed and the measured temperature, and the time period being constant.

4. A display panel (1) as claimed in claim 2 characterized in that the drive means (100) are able to control each duration to consist of a number of intervals of equal time period, the number being determined by the picture to be displayed and the time period being determined by the measured temperature.

5. A display panel (1) as claimed in claim 1 characterized in that the drive means (100) are able to control the levels in dependence of the measured temperature.

6. A display panel (1) as claimed in any one of the preceding claims, characterized in that the first substrate (8) comprises the first electrodes (3), and the second substrate (9) comprises the second electrodes (4).


8
8
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9
9
3
5'
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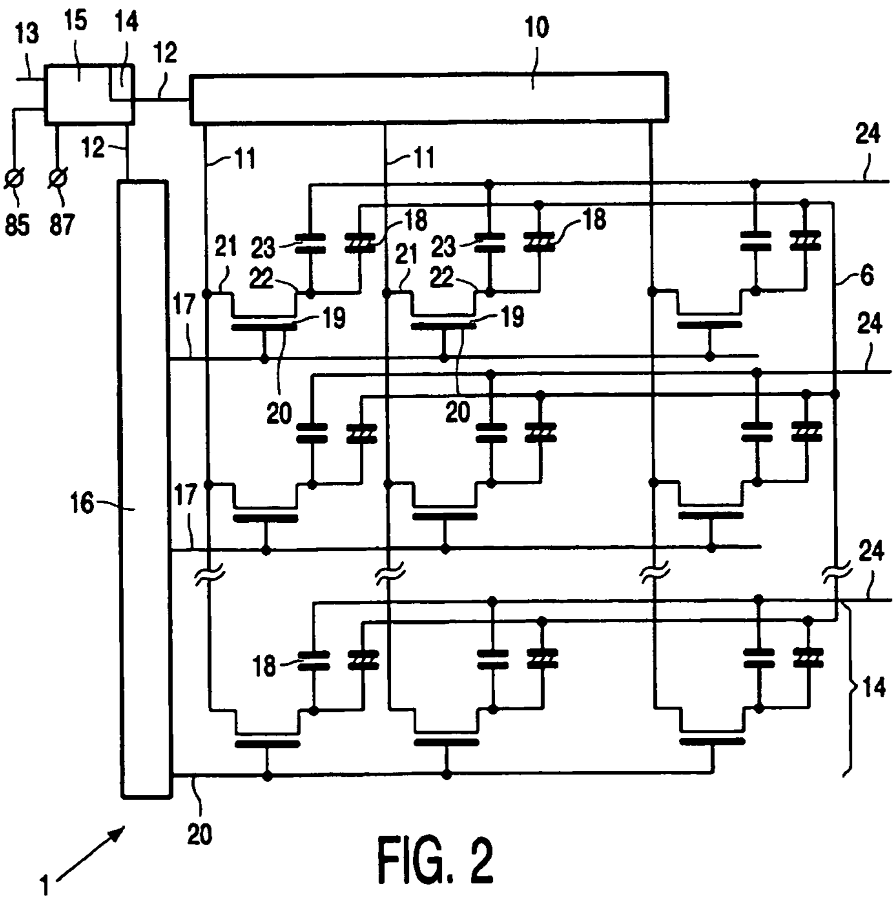
2
1

FIG. 1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15
14
12
10
12
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14
1

FIG. 2

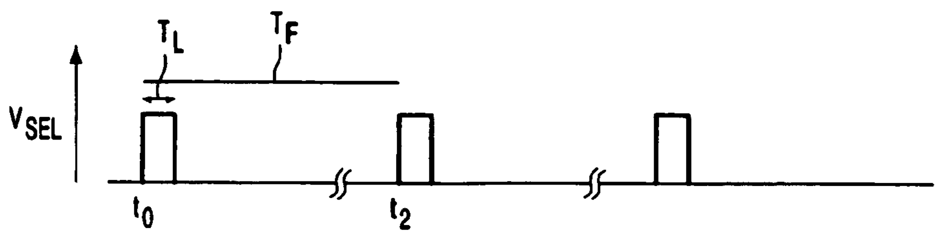


FIG. 3

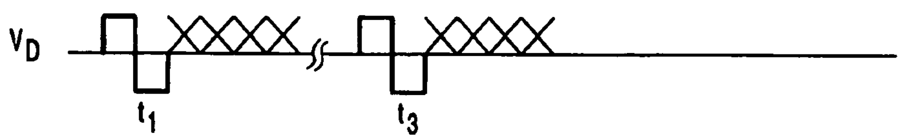


FIG. 4

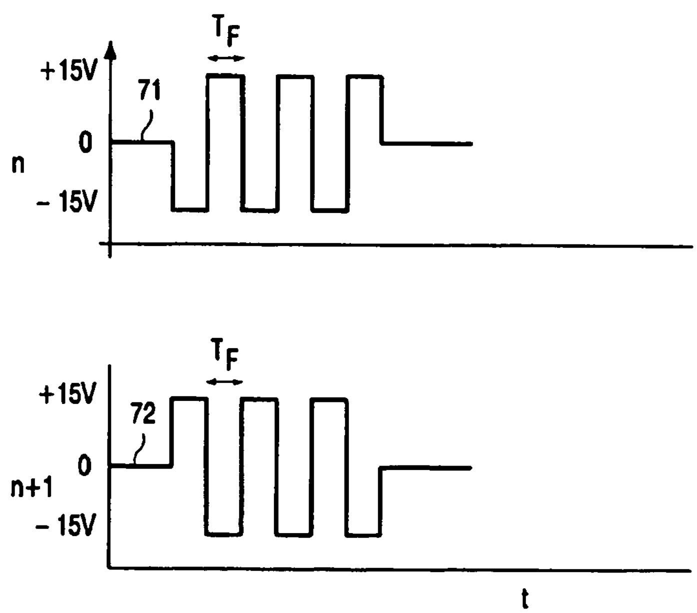


FIG. 7

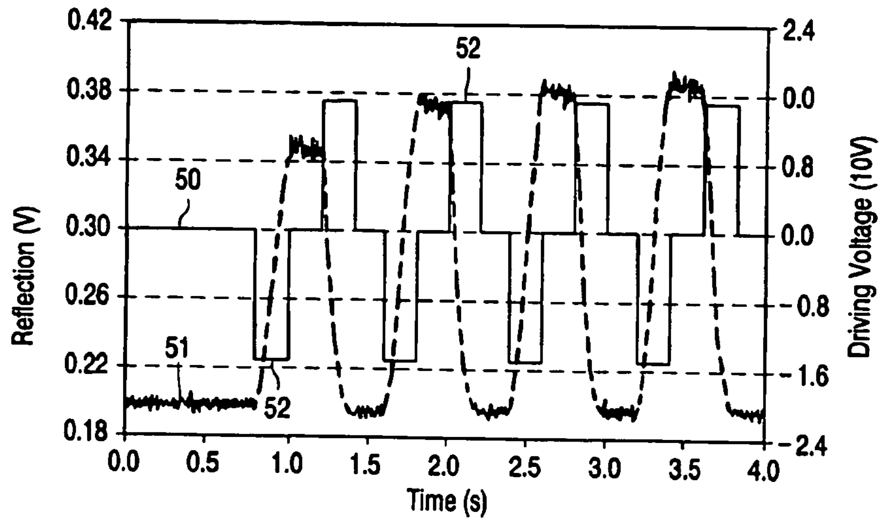

0.42
0.38
0.34
0.30
0.26
0.22
0.18
Reflection (V)
2.4
0.0
0.8
0.0
-0.8
-1.6
-2.4
Driving Voltage (10V)
50
51
52
52
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (s)

FIG. 5

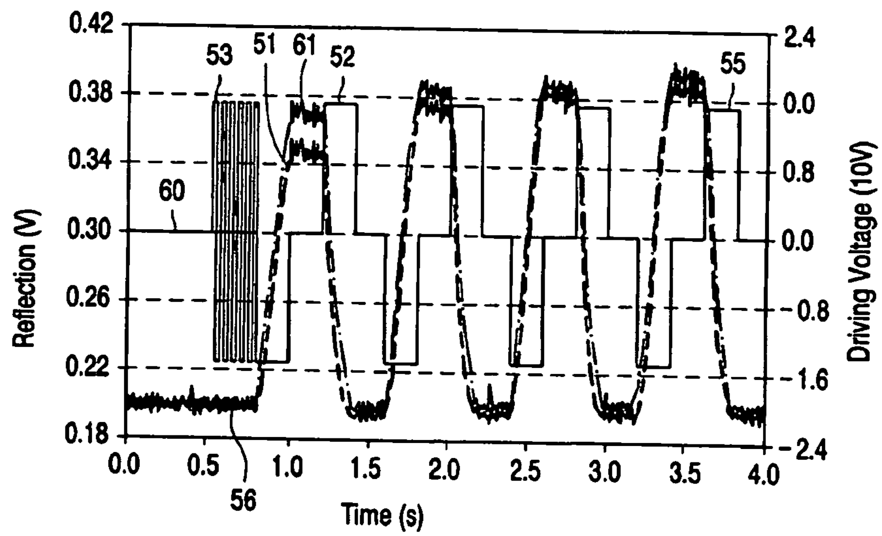

0.42
0.38
0.34
0.30
0.26
0.22
0.18
Reflection (V)
2.4
0.0
0.8
0.0
-0.8
-1.6
-2.4
Driving Voltage (10V)
53
51
61
52
55
60
56
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (s)

FIG. 6

PHNL020441

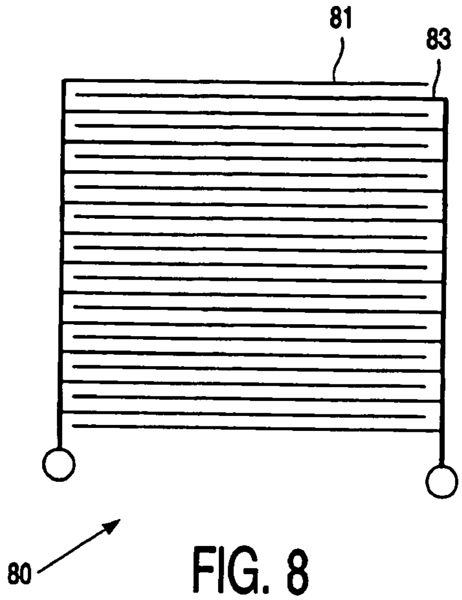


FIG. 8

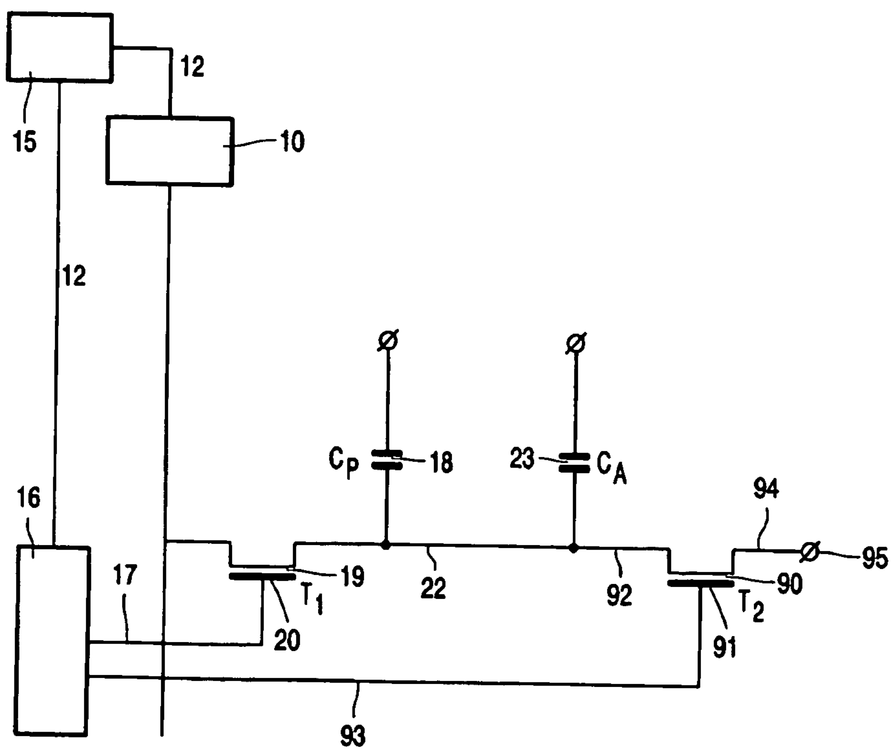


FIG. 9

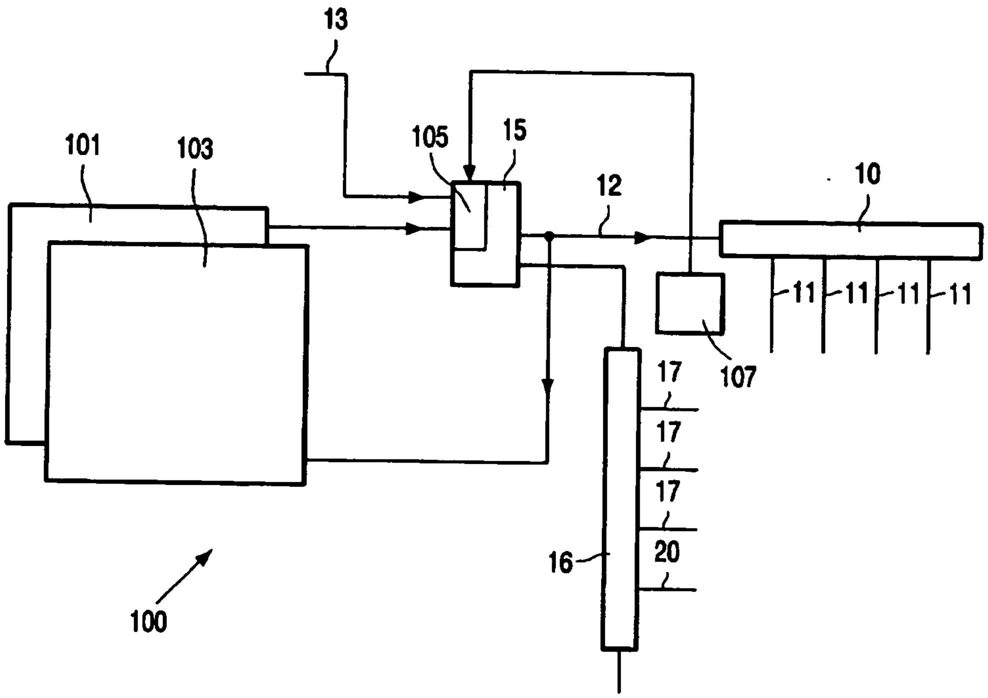

13
105
15
101
103
12
10
11
11
11
11
107
17
17
17
20
16
100

FIG. 10

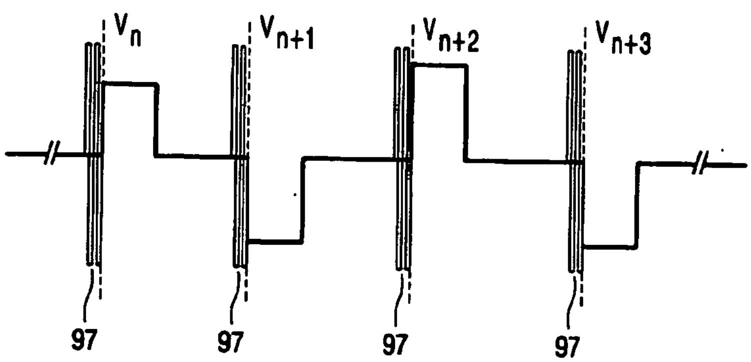

V_n
V_{n+1}
V_{n+2}
V_{n+3}
97
97
97
97

FIG. 11

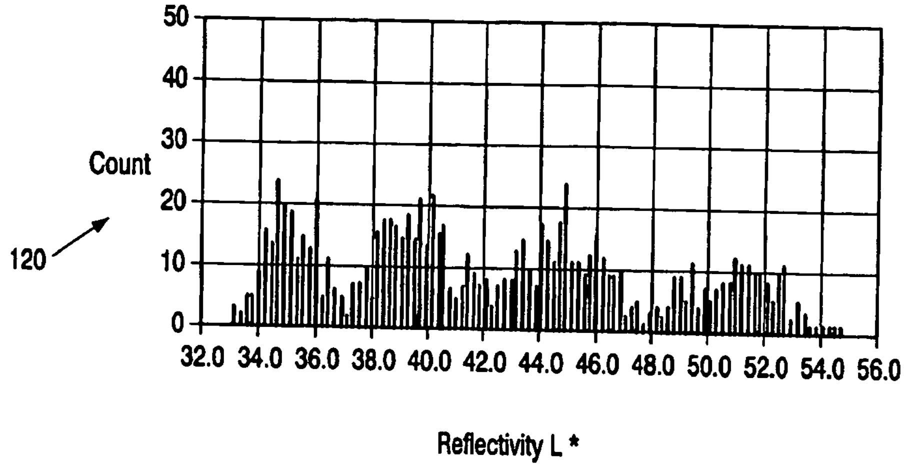

50
40
30
Count
20
10
0
120
32.0 34.0 36.0 38.0 40.0 42.0 44.0 46.0 48.0 50.0 52.0 54.0 56.0
Reflectivity L *

FIG. 12

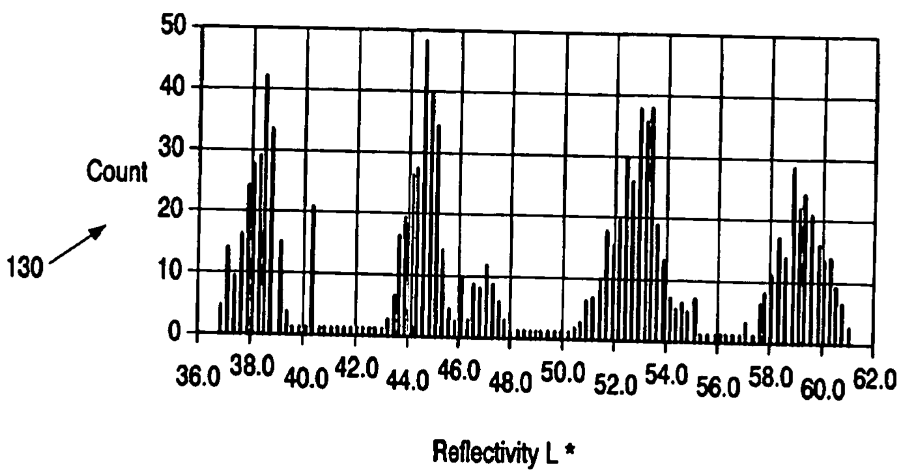

50
40
30
Count
20
10
0
130
36.0 38.0 40.0 42.0 44.0 46.0 48.0 50.0 52.0 54.0 56.0 58.0 60.0 62.0
Reflectivity L *

FIG. 13

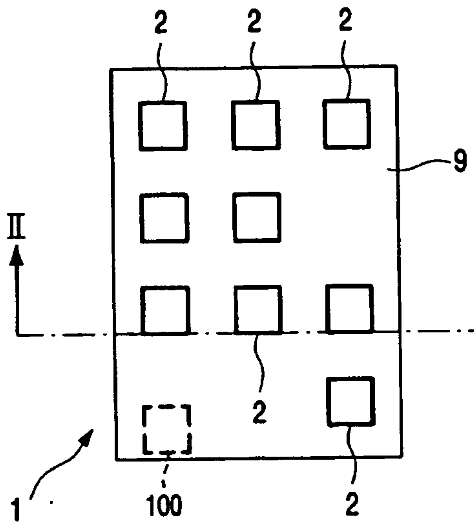


FIG. 1

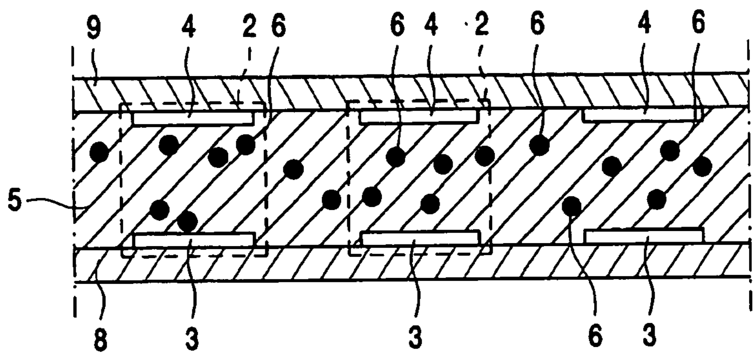


FIG. 2

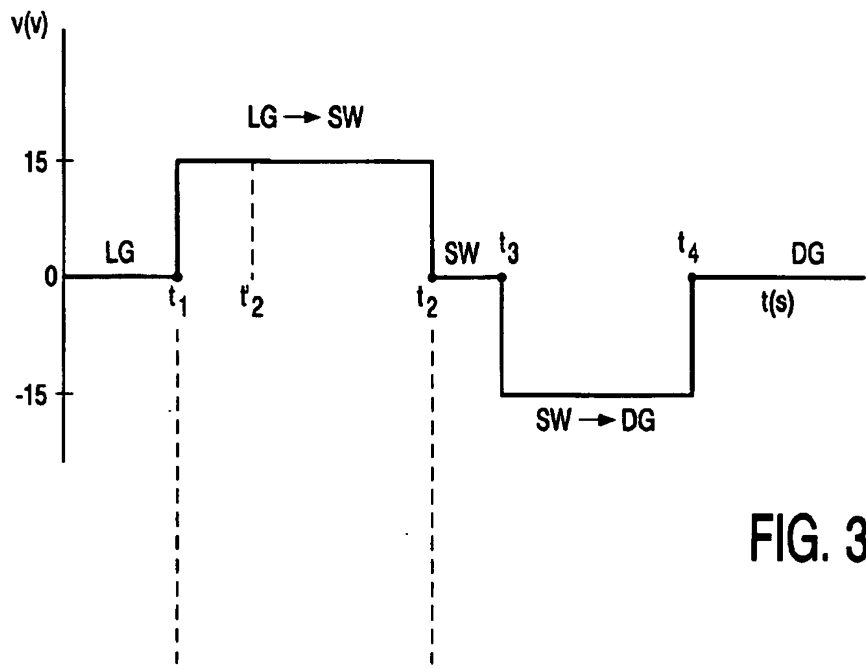

v(v)
LG → SW
15
LG
0
-15
SW
t_3
t_4
DG
t_1
t'_2
t_2
t(s)
SW → DG

FIG. 3A

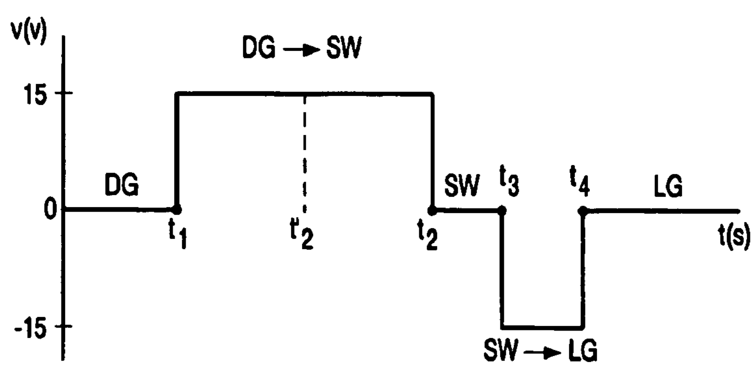

v(v)
DG → SW
15
DG
0
-15
SW
t_3
t_4
LG
t_1
t'_2
t_2
t(s)
SW → LG

FIG. 3B

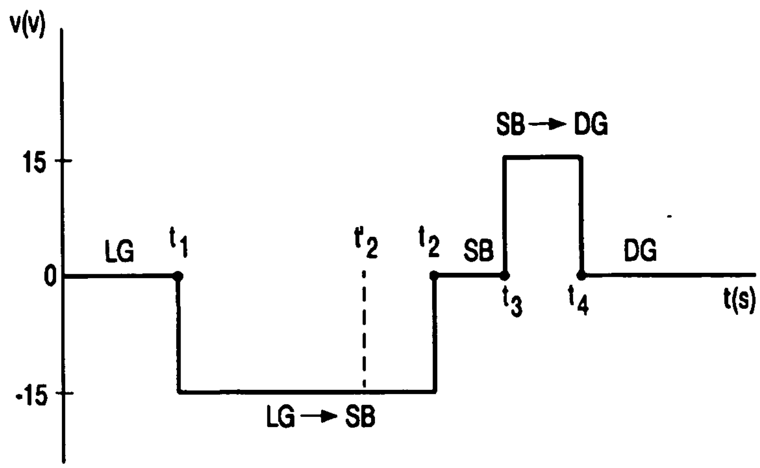

v(v)
15
0
-15
SB → DG
LG
t_1
t'_2
t_2
SB
t_3
t_4
DG
t(s)
LG → SB

FIG. 4A

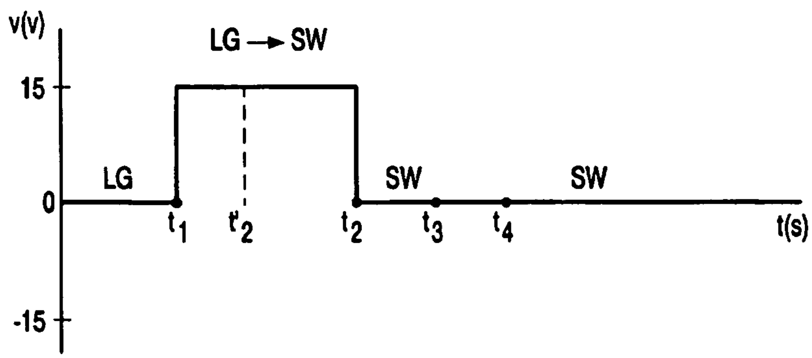

v(v)
LG → SW
15
0
-15
LG
SW
SW
t_1
t'_2
t_2
t_3
t_4
t(s)

FIG. 4B

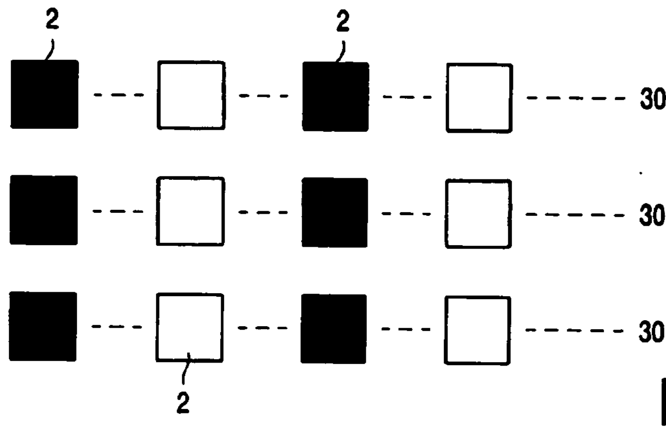


FIG. 5

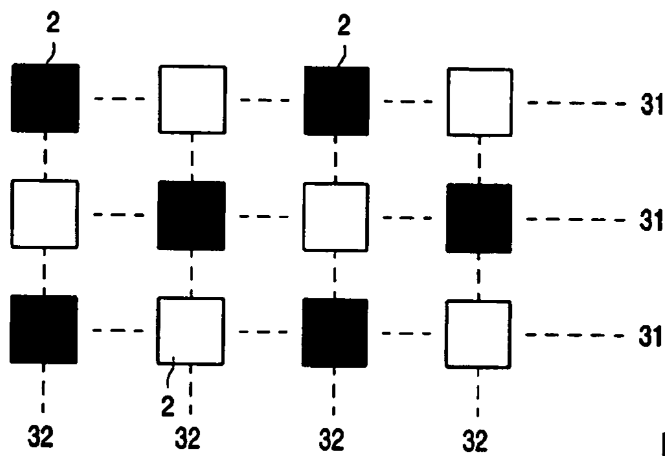


FIG. 6

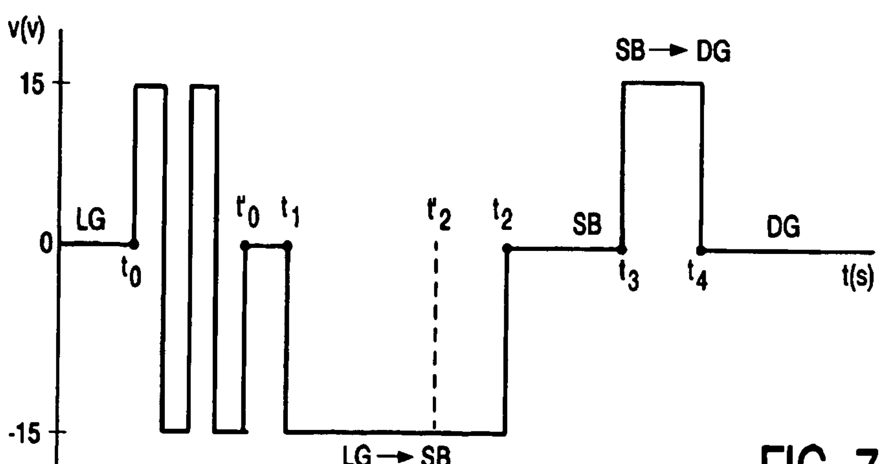


FIG. 7

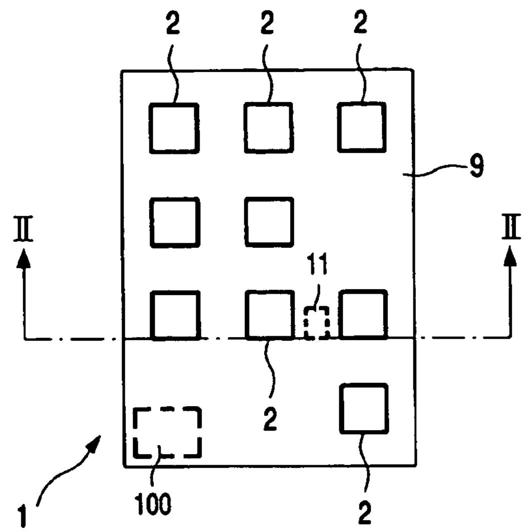


FIG. 1

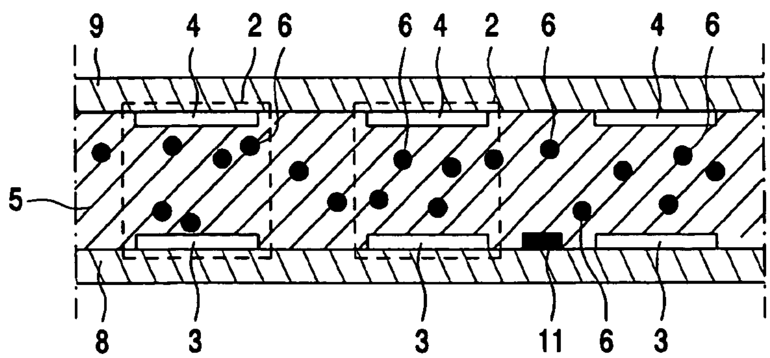
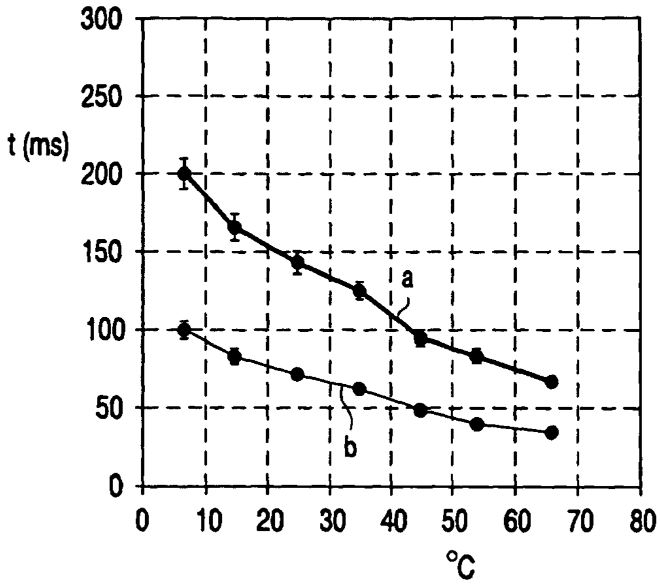
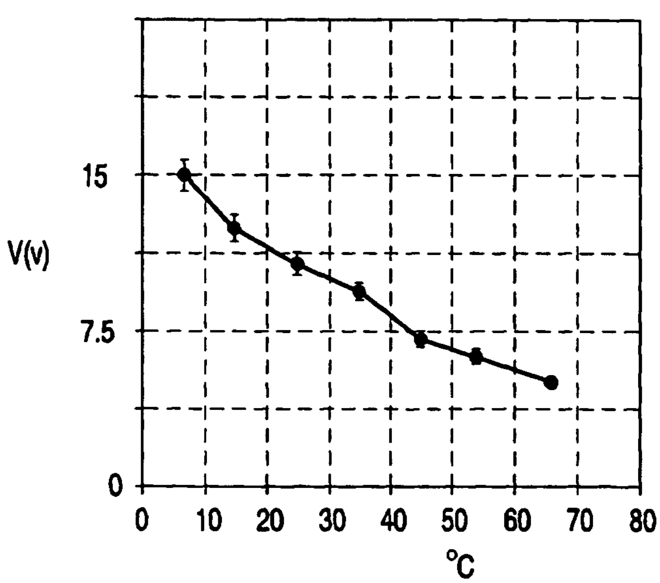


FIG. 2



t (ms)
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
°C
a
b

FIG. 3



V(v)
15
7.5
0
0
10
20
30
40
50
60
70
80
°C

FIG. 4

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of
Guofu Zhou, et.al.
Serial No.:
Filed: CONCURRENTLY

Atty. Docket
US030309
Group Art Unit:

Title: DRIVING METHOD FOR AN ELECTROPHORETIC DISPLAY WITH HIGH FRAME RATE AND LOW POWER CONSUMPTION

Honorable Commissioner of Patents
Alexandria, VA 22313

APPOINTMENT OF ASSOCIATES

Sir:

The undersigned Attorney of Record hereby revokes all prior appointments (if any) of Associate Attorney(s) or Agent(s) in the above-captioned case and appoints:

FRANK KEEGAN **(Registration No. 50,145) and**

MICHAEL MARION **(Registration No. 32,266)**

c/o PHILIPS INTELLECTUAL PROPERTY & STANDARDS, P.O. Box 3001, New York 10510, his Associate Attorney(s)/Agent(s) with all the usual powers to prosecute the above-identified application and any division or continuation thereof, to make alterations and amendments therein, and to transact all business in the Patent and Trademark Office connected therewith.

ALL CORRESPONDENCE CONCERNING THIS APPLICATION AND THE LETTERS PATENT WHEN GRANTED SHOULD BE ADDRESSED TO THE UNDERSIGNED ATTORNEY OF RECORD.

Respectfully,

Michael E. Marion

Michael E. Marion, Reg. 32,266
Attorney of Record

Dated at Tarrytown, New York
on September 8, 2003.